Box 1316

A SYSTEM OF PHILOSOPHY.

THE PRINCIPLES

OF

PSYCHOLOGY.

PART I.

THE DATA OF PSYCHOLOGY.

BY

HERBERT SPENCER.

NEW YORK:
D. APPLETON AND COMPANY,
90, 92 AND 94 GRAND STREET.
1869.

3/5

A SYSTEM OF PHILOSOPHY.

BY HERBERT SPENCER.

In 1860, Mr. Herbert Spencer published the prospectus of a System of Philosophy, original in method, and more comprehensive in scope than any thing which had been hitherto attempted. It proposed nothing less than to develop a complete scheme of scientific principles, which should embrace, in one plan of treatment, the subjects of Life, Mind, Society, and Morality. It embraced five divisions: I. First Principles; II. The Principles of Biology; III. The Principles of Psychology; IV. The Principles of Sociology; V. The Principles of Morality.

The project was naturally looked upon by many as chimerical. The term "Philosophy" had been so long applied to speculations upon remote and transcendental questions, incapable of settlement, that a strong prejudice existed against any thing calling itself by the name; so that the announcement of a new philosophical system was looked upon as promising, not a contribution to real knowledge, but only as a fresh display of futile ingenuity in an exhausted and a hopeless field. It was besides thought impossible to reduce such diverse subjects to any thing like a philosophical unity of treatment, while the task, even if possible, was held to be beyond the power of any single mind to accomplish.

Uninfluenced by these considerations, Mr. Spencer went forward with his plan, which is now so far advanced as to justify the expectation that it will be fully carried out. Of its five projected divisions, two—"First Principles," in one volume, and the "Principles of Biology," in two volumes—are completed. The author has now entered upon the third division, and the first portion of it—the Data of Psychology—is published. The successive portions will be issued in this country simultaneously with their appearance in England.

That Mr. Spencer has not entered upon the pursuit of a chimera, but upon the solution of a problem, which, though vast, is still practicable, will be apparent when we consider his point of view. By "Philosophy," he understands the deepest explanation of the universe at which man can arrive. The sev-

eral sciences give us separate explanations of the facts of the world. Philosophy seeks, by coördinating these explanations, to evolve universal principles, or an interpretation of the complete order of Nature; and, resting upon a basis of demonstrated truth, it has a validity derived from the certainty of these truths.

It is the tendency of all science to disclose a unity in the method of Nature: philosophy, therefore, becomes an expression of that unity, and it may accordingly be defined as the highest unification of knowledge. But this unity must not be a mere invention or anticipation of the imagination; it must spring from the operation of universal law, which each of the sciences can attest in its own sphere. Mr. Spencer finds the principle, which has been growing into greatest clearness during the present century in all departments of investigation, to be the Law of Evolution. Affirmed in astronomy, revealed in geology, familiar in the worlds of vegetable and animal life, immanent in the sphere of mind, and equally manifest in the development of society and the progress of the arts of civilization, Mr. Spencer has worked it out as the basis of a philosophy the aim of which is to trace out the universal laws to which phenomena conform.

But, though not impossible, it is evident that only a mind of rare endowments could give promise of succeeding in so vast an undertaking. An accurate and extensive acquaintance with science must be joined with a comprehensive mental grasp and a large capacity of generalization. There must besides be great boldness, independence, and originality of thought, and such a passionate love of truth as will enable a man to consecrate his life to a work with which his age has little sympathy.

Mr. Spencer combines these qualities in a very remarkable degree. Perhaps, in the whole range of scientific and philosophic literature, nothing more clear, comprehensive, original, and profound, has yet appeared than those parts of his philosophical system which are now before the world. If this statement is objected to, as only an individual opinion, it is easily reënforced by authorities that will not be questioned.

As an indication of the esteem in which Mr. Spencer is held on the Continent, it may be mentioned that all his works are now being translated into Russian and published at St. Petersburg, by M. Thieblin, and that three translators, all Professors of Philosophy, are now occupied in rendering them into French: Doctor Cazelles has translated "First Principles," and is now engaged upon the "Biology;" Professor Ribot, of the *Lycée Imperial*, Laval, is translating the "Principles of Psychology;" and Professor Péthoré, of the *Lycée Imperial*, Angoulême, is occupied with the "Education" and the "Classification of the Sciences."

We cannot here offer any recent opinions of the English press on Mr. Spencer's *System of Philosophy*, for the sufficient reason that he has of late sent out no copies of his work for review.* The misstatements made by critics, who were either too idle to read his books or incompetent to form estimates of them, he had from the beginning taken as things to be expected and endured. Not long ago, however, he found, from personal testimony, that even those most interested in some of the topics treated by him had for years been deterred from looking at his works by the false impressions which press-notices had given to them. On learning this, he concluded that it would be best no longer to give occasion for these misleading criticisms. Neither of his last two volumes has been issued to the newspapers or the literary journals, and his English publishers have now a standing order not to send out for review any future work of his.

But, though no indorsement by anonymous critics can be cited, we may cite indorsements of much greater weight; the publicly-expressed opinions of well-known men thoroughly competent to judge. The reader's attention is asked to the following extracts from works published by authors whose names are given.

Prof. Masson, *of the University of Edinburgh.*

"No such defect can be charged against the other writer whom I am now to name—Mr. Herbert Spencer. Of all our thinkers he is the one who, as it appears to me, has formed to himself the largest new scheme of a systematic philosophy, and, in relation to some of the greatest questions of Philosophy in their most recent forms, as set or reset by the last speculations and revelations of science, has already shot his thoughts the farthest. He both works out his Philosophy physiologically and psychologically from the centre, and—what seems to me an eminent merit in relation to the intellectual needs of the time—surveys it and contemplates it from the circumference cosmologically. Indeed, I should say that he is the British thinker who has most distinctly realized the absolute necessity that Philosophy lies under, of dealing with the total cosmological conception as well as with the mere psychical or physiological organism (and this from the demonstrable inter-relatedness of both), if it would grasp all the present throbbings of the speculative intellect. His writings take for granted this necessity, and make it plainer than it would otherwise be. Nowhere else are the various sciences so fished for generlizations that may come together as a whole to help in forming a Philosophy. Nowhere else, at all events, is there a more beautiful and fearless exposition of some of those recent scientific notions which I spoke of in the last chapter as affecting our views of metaphysical problems.

* Nevertheless, incidental references constantly occur in the leading periodicals, which show the position Mr. Spencer has won in the world of thought. The very last number of the *Saturday Review*, for example, has the following: "If we were to give our own judgment, we should say that, since Newton, there has not in England been a philosopher of more remarkable speculative and systematizing talent than (in spite of some errors and some narrowness) Mr. Herbert Spencer."—*London Saturday Review, Feb.* 6, 1869.

There are parts of Mr. Spencer's writings, occupied with such expositions, which, from sheer scientific clearness, and adequacy of language to the matter, have all the effect of a poem. If even only for such renderings of high scientific conceptions, on the chance of their somehow taking possession of the popular soul, and uniting there to rectify previous forms of thought, he would deserve honorable recognition.

"But Mr. Spencer does not stop short in the character of an interpreter between Science and Philosophy, handing on the conceptions of Science to that congress of all the Powers, where they are to be adjusted and take effect. He assumes the work of the philosopher proper. He seeks to enmesh the physical round of things, as Science now orbs it to the instructed imagination, within a competent Metaphysic; he desires to fix in the centre a competent Psychology, consistent with this Metaphysic, and yet empirically and physiologically educed; and he would fill up the interior, or what of it the physical sciences leave void, with a competent Ethics, a competent Jurisprudence, a competent Æsthetics, a competent Science of Government and Politics.

"In this great work he is still engaged; and it will not perhaps be till the whole is accomplished that there will be the means of determining either the sufficiency of Mr. Spencer's philosophy for the higher practical purposes of philosophy, or its exact intellectual relations to previous systems. Already, in consequence both of the decisiveness of his views and the variety of interesting subjects over which they extend, Mr. Spencer, more than any other systematic British thinker save Mill, has an avowed following both here and in America; and, if any individual influence is visibly encroaching on Mill's in this country, it is his. For my own part, believing that no type of man ought to be more precious to a nation than a resolute systematic thinker, and believing Mr. Spencer to be a very high specimen of this type, I anticipate nothing but good—nothing, at least, but a clearing away of the bad—from what he has already done, or may yet do."—*Recent British Philosophy*, Chapter iv.

Mr. John Stuart Mill.

"The last extract is from Mr. Herbert Spencer, whose Principles of Psychology, in spite of some doctrines which he holds in common with the intuitive school, are, on the whole, one of the finest examples we possess of the Psychological method in its full power."—Mills Hamilton, Chapter xiii.—"One of the acutest Metaphysicians of modern times."—*Ibid.*, chapter ii.

"Mr. Spencer is one of the small number of persons who, by the solidity and encyclopædical character of their knowledge, and their power of coördination and concatenation, may claim to be peers of M. Comte, and entitled to a vote in the estimate of him."—*Mill's Review of Comte.*—"One of the most vigorous as well as boldest thinkers that English speculation has yet produced."—*Ibid.*

M. Laugel.

"The great work on Philosophy by Herbert Spencer, whom I would style the last of English Metaphysicians. In the midst of universal indifference, Mr. Spencer remained steadily attached to his philosophical studies, displaying all that heroic courage and that rare independence indispensable to those who devote themselves to toilsome researches which at best only recompense the student with a few obscure and isolated suf-

frages. If Mr. Spencer, with his talents, his fertility of genius, and the almost encyclopædic variety of knowledge of which his writings furnish the proof, had chosen to follow the beaten path, nothing would have been more easy than for him to secure all those honors of which English society is so prodigal to those who serve her as she wishes to be served. He preferred, however, with a noble and touching self-denial, to put up with poverty, and, what is still more difficult, with obscurity. But he deserves more than vain assurances of sympathy: we must not merely admire his fidelity to profitless studies; his work itself merits the individual attention of all friends of Philosophy."—*Revue des Deux Mondes, of February* 15, 1864.

Prof. T. H. HUXLEY, F. R. S., LL. D.

"Those who hold the doctrine of Evolution (and I am one of them) conceive that there are grounds for believing that the world, with all that is in it and on it, did not come into existence in the condition in which we now see it, nor in any thing approaching that condition.

"On the contrary, they hold that the present conformation and composition of the earth's crust, the distribution of land and water, and the infinitely diversified forms of animals and plants which constitute its present population, are merely the final terms in an immense series of changes which have been brought about, in the course of immeasurable time, by the operation of causes more or less familiar to those which are at work at the present day.

"Perhaps this doctrine of Evolution is not maintained consciously and in its logical integrity by a very great number of persons. The only complete and systematic statement of the doctrine with which I am acquainted is that contained in Mr. Herbert Spencer's 'System of Philosophy;' a work which should be carefully studied by all who desire to know whither scientific thought is tending."—*Lecture before the Royal Institute of Great Britian.*

JAMES McCOSH, D. D., LL. D.

"In the new edition of his 'Intuitions of Mind,' Dr. McCosh devotes a chapter to Spencer's Philosophy. But, 'great as are the author's intellectual powers,' he believes that its success is beyond the reach of this 'giant mind,' and indeed beyond the present possibility of science. Yet he observes: 'This in regard to his theory as a whole; but his bold generalizations are always suggestive, and some may in the end be established as the profoundest laws of the knowable universe.'"

JOSEPH D. HOOKER, F. R. S., LL. D.

"Another instance of successful experiment in Physiological Botany is Mr. Herbert Spencer's observations on the circulation of the sap and the formation of wood in plants. As is well known, the tissues of our herbs, shrubs, and trees, from the tips of their roots to those of their petals and pistils, are permeated by tubular vessels. The functions of these have been hotly disputed, some physiologists affirming that they convey air, others fluids, others gases, and still others assigning to them far-fetched uses, of a wholly different nature. By a series of admirably contrived and conducted experiments, Mr. Spencer has shown not only that these

vessels are charged at certain seasons of the year with fluid, but that they are intimately connected with the formation of wood. He further investigates the nature of the special tissues concerned in this operation, and shows not merely how they may act, but to a great extent how they do act. As this paper will, I believe, be especially alluded to by the President of the Biological Section, I need dwell no further on it here, than to quote it as an example of what may be done by an acute observer and experimentalist, versed in physics and chemistry, but, above all, thoroughly instructed in scientific methods."—*Inaugural Address at Meeting of British Association*, 1868.

"One of our deepest thinkers, Mr. Herbert Spencer."—*Ibid.*

George Henry Lewes.

"This last-named writer (Mr. Spencer) is now daily rising into wider influence. * * * Even antagonists are compelled to admit the force and clearness of his genius, and the extent and profundity of his scientific knowledge. It is questionable whether any thinker of finer calibre has appeared in our country, although the future alone is to determine the position he is to assume in history. * * * He alone, of all British thinkers, has organized a philosophy."—*History of Philosophy*, vol. ii., p. 653.

J. D. Morrell, LL. D.

"Mr. Spencer is equally remarkable for his search after first principles; for his acute attempts to decompose mental phenomena into their primary elements; and for his broad generalizations of mental activity, viewed in connection with nature, instinct, and all the analogies presented by life in its universal aspects."—*Medico-chirurgical Review*.

Dr. Francis Wayland, *late President of Brown University.*

"I have read Herbert Spencer through, and some of the Essays twice. His volume on Education will do much to change the opinions of the civilized world. I hope it will be widely read here and in England. As to the worth of knowledge, he is very strong; here he and I are aiming at the same thing. I did not expect to see in my day any one with whose views I could so sincerely sympathize. He speaks to the common sense of humanity, and hates sham; and he will triumph, though it will take some time first."—*Life of Dr. Wayland*, vol. ii., p. 294.

J. G. Macvicar, D. D.

"An author who is both extensively and profoundly versed in science, and who writes, on all the subjects which he handles, with great power, equally of observation, abstraction, and generalization: for such is Herbert Spencer, author of a 'System of Philosophy,' now in course of publication."—*Mind: its Powers and Capacities*, p. 9.

PART I.

THE DATA OF PSYCHOLOGY.

CHAPTER I.

THE NERVOUS SYSTEM.

§ 1. The lowest animal and the highest animal present no contrast more striking than that between the small self-mobility of the one and the great self-mobility of the other. A monad passing, apparently with some rapidity, across the field of the microscope, really advances with extreme slowness: its velocity, unexaggerated by combined lenses, being about that of the minute-hand of a watch. The parts of a disturbed sea-anemone draw themselves together with a speed which, though immensely greater than that of a monad through the water, is insignificant as measured by the speed of most terrestrial and aerial creatures. Comparing the movements of *Protozoa*, or of *Zoophytes*, with those of Birds that keep pace with railway trains or those Mammals that gallop a mile in a minute, their locomotive powers seem scarcely appreciable. Masses being supposed equal, the quantity of motion generated in the last case approaches a million times that generated in the first.

Contrasts of this kind exist within each great division of the animal kingdom, as well as in the animal kingdom taken as a whole. The sub-kingdom *Annulosa* shows us an immense difference between the slow crawling of worms and quick flight of insects. Among Mollusks the sluggishness of the *Tunicata* is no less marked than the activity of the *Cephalopoda*. And between the inferior or water-

breathing *Vertebrata* and superior or air-breathing *Vertebrata,* there is an equally conspicuous unlikeness in energy of movement.

This self-mobility which by its greater amount generally distinguishes higher animals from lower, and, indeed, enters largely into our conceptions of higher and lower, is displayed in several ways. We see it in the changes of attitude that are made without moving the body from place to place. We see it in the transference of the body as a whole through space: considering this transference apart from external resistances overcome. And we see it in the overcoming of resistances—both those of media and those due to gravity. All these, however, are manifestations of one ability—the ability to generate a force which either shows itself as momentum or would generate momentum but for a counterbalancing force. And it is in this general form that we are here concerned with this ability. We have to contemplate the inferior animals as being generators of very small quantities of actual or potential motion, and the higher animals as being generators of relatively-immense quantities of actual or potential motion.

§ 2. With what internal differences are these differences of external manifestation connected? No doubt with several. An active organism contains various appliances no one of which can be spared without greatly diminishing, or quite destroying, its activity.

If the alimentary system be incapacitated, there must presently result a decreased power of generating motion, from lack of the materials whence motion is obtained; and hence the fact, conspicuous throughout the animal kingdom, that along with much locomotive activity there goes a developed apparatus for taking up nutriment. It is manifest, too, that there cannot be great self-mobility unless the absorbed materials are efficiently distributed to the organs which transform insensible motion into sensible motion; and thus

it happens that as we ascend from creatures which move little to creatures which move much, we meet with a more and more evolved vascular system. Similarly with the organs for separating from the blood the substances that have yielded up their contained motion. If the blood becomes choked with inert matter, there necessarily results a decreased genesis of motion; and therefore, as we see on comparing inactive with active animals, the exaltation of activity is accompanied by the development of depurating structures. Still clearer is it that the production of much motion, and the resistance to those forces which antagonize motion, imply parts capable of bearing great strains—masses of dense tissue such as in vertebrate animals form bones, and in invertebrate animals form dermal frameworks; and, accordingly, as we ascend from creatures that are inert to creatures that are vivacious, we advance from weak to strong skeletons, internal or external. Above all it is self-evident that along with locomotive activity there must exist those contractile organs which are the immediate movers of the limbs and consequently of the body; and hence the direct connection between absence of muscular fibres and extremely-small self-mobility, and the direct connection between development of the muscles and much self-mobility—connections so direct as to make it at first sight seem that the genesis of motion varies as the muscular development.

Remotely dependent, however, as the genesis of motion is on digestive, vascular, respiratory, and other structures; and immediately dependent as it is on contractile structures; its most important dependence remains to be named. For all of these appliances taken together can do nothing of themselves. The muscles are but instruments, which remain passive until their power is evoked by the structure which uses them; and the quantity of motion they then give out varies according to the demand made by this exciting and controlling structure. In other words, the

initiator or primary generator of motion is the Nervous System. Where there is extremely little power of generating motion, as among the *Protozoa* and the inferior *Cœlenterata,* there is no nervous system. Where activity begins to show itself a nervous system begins to be visible. And where the power of self-movement is great, the nervous system is comparatively well developed. Though the muscular system also becomes larger and better organized; yet the quantity of motion produced is fundamentally related to the degree of nervous development. Not, indeed, that it is so related with anything like uniformity: this we shall presently see that it cannot be. But it is so related more uniformly than in any other way. A few typical contrasts will show this.

§ 3. The absence of measurements renders detailed comparison among the various classes of *Mollusca* unsatisfactory. On putting side by side the extreme terms, however, we find an unquestionable difference in the proportion between the nervous system and the rest of the body. The sedentary Ascidians, which do little in the way of moving beyond occasionally contracting themselves, severally possess only a single small ganglion with its fibres; but Cephalopods of the dibranchiate order, which are active creatures that dart through the water fast enough to catch fish, contain masses of nerve-tissue that bear much larger ratios to their total masses.

It is with annulose animals as with molluscous animals—we have no definite estimates of the sizes of their nervous systems; and hence can bring in evidence only the marked differences. As before, the extreme forms supply these. The sluggish annuloid types, when contrasted with the energetic kinds of *Annulosa,* present decided deficiencies of nerve-substance; and even between such less-remote orders as the tubicolous Annelids, leading stationary lives, and the decapodous Crustaceans, leading active lives, a kindred

difference may be safely asserted. There are also, in some annulose types contrasts between the nervous system in the inactive and active stages of the same individual. The feebly-moving caterpillar has but a small nervous system; the butterfly, with its power of vigorous flight, has a relatively large one; and during the intermediate pupa-state, in which the organization is being adapted to this more vivacious life, a rapid growth of the nervous system may be traced.

It is in the *Vertebrata*, however, that the most striking evidence meets us. According to Leuret, the average ratio of the brain to the body is—in fishes, 1 to 5,668; in reptiles, 1 to 1,321; in birds, 1 to 212; and in mammals, 1 to 186. Now though these can be but rude approximations, since there are great differences within each class, and since the ratio of the brain to the body is not the ratio of the whole nervous system to the body; yet the relations they indicate are substantially true. Were the weight of the spinal cord and the nerves added to that of the brain in each case, the strengths of the contrasts would be considerably diminished; but the contrasts would still be strong. And with them there go the strong contrasts between the activities in the respective classes—the Fishes that swim in a medium of their own specific gravity; the Reptiles of which the higher have to support the weights of their bodies as they move about over the land, but cannot do this for long together; the Birds and Mammals that are in constant locomotion, often at high velocities. Here, too, the alleged connection is rendered the clearer by the approximate uniformity of the relative amount of muscle. The weight of muscle in a fish forms something like as large a part of the total weight as it does in a reptile—perhaps a larger part; and a reptile is scarcely if at all inferior to a bird or a mammal in the proportion of contractile tissue it possesses. Hence it becomes manifest that indispensable as is contractile tissue to the genesis of motion, its quantity does not determine the quantity of

motion generated. Whereas, notwithstanding the many complicating circumstances, a general relation between quantity of nerve and quantity of motion is traceable.

There are special cases which illustrate this relation. I may name one—the case of the Porpoise. A Porpoise's brain exceeds greatly in size the brains of other Mammals that have bodies commensurate with its own, except that of Man and, perhaps, that of the Gorilla. Such a structure in a creature leading so simple a life, is a serious difficulty in the way of current interpretations; but is quite in harmony with the interpretation here given. Porpoises accompanying a steam-vessel, gambolling and making excursions on either side without apparent effort, prove, by keeping up so high a velocity through so dense a medium, that their motor energies are enormous.

§ 4. A closer examination of the facts soon reveals the insufficiency of the foregoing generalization. Deep as is the connection between nervous development and locomotive activity, further comparisons show that it is complicated with some other connection scarcely less radical. If, other things being equal, the quantity of motion generated varied directly as the quantity of nerve-tissue, then, in creatures constitutionally alike or but little dissimilar, a tolerably constant ratio would exist between the mass of the nervous system and the mass of the body: supposing the body, whether large or small, to be carried from place to place with equal velocity. The ratio is far from constant however.

A horse gallops much faster than a man runs; and a horse in ordinary work daily moves his body through a space greater than that through which a man moves his body, or greater than that transposition of his body which a man's daily labour is equivalent to. Hence were there a simple relation between amount of nerve-tissue and amount of motion evolved, a horse, which weighs some seven times as much

as a man, should have a nervous system at least seven times as heavy. Instead of this it has a lighter nervous system. Its brain weighs but one pound seven ounces; and were its spinal cord added, the total weight would probably not exceed two pounds. But a man's brain and spinal cord weigh between three and four pounds. Thus the horse's cerebro-spinal axis is but one-tenth of what it should be, were this relation the only one. Still clearer is the proof that there is some other relation, when we avoid modifying causes, by comparing animals of the same genus, or species, but of different sizes. The varieties of dogs supply good illustrations. A newfoundland and a spaniel are alike in organization, food, temperature, respiration, &c.; and they are approximately alike in their powers of locomotion: the advantage being on the side of the larger of the two. Were genesis of motion measured by quantity of nerve-tissue, a newfoundland's cerebro-spinal axis should, therefore, exceed in size that of a spaniel as much as a newfoundland's body exceeds in size that of a spaniel. But it by no means does so. While considerably larger absolutely, it is much smaller relatively.

Consequently, we must say that though the nervous system is the initiator of motion, and though there is evidently some relation between degree of nervous development and degree of motor energy; yet this relation is involved with, and obscured by, another. Let us re-examine the facts in search of it.

§ 5. In what other way than in relative feebleness, do the motions of inferior creatures differ from those of superior creatures? They differ in relative simplicity. Animals that are but little evolved perform actions which, besides being slow, are few in kind and severally uniform in composition. Animals that are much evolved perform actions which, besides being rapid, are numerous in kind and severally involved in composition. The movements in the one

case are small and homogeneous, and in the other case great and heterogeneous. Each sub-kingdom of animals exemplifies this second general relation, as much as it does the first.

Humble Mollusks, like the fixed *Tunicata*, display scarcely any energies beyond those required to contract their bodies when disturbed and afterwards to unfold them. But in the highly-organized Cuttle-fishes, besides the rapid, quickly-varied, and well-adjusted movements exhibited in the pursuit and capture of prey, we have the numerous and combined movements of the suckered arms, used not only for prehension but occasionally for travelling over solid surfaces.

The *Annulosa*, including with them the *Annuloida*, supply a like general contrast. Between the uniform, little-varied motions of a Nemertine worm, and the multiform, variously-combined motions of the Crab or the Spider, the difference is paralleled by the difference in nervous evolution. And a like structural contrast accompanies the contrast between the few simple actions of the caterpillar and the numerous complex actions of the butterfly.

But that heterogeneity of movement increases along with relative size of the nervous system, is best shown by comparisons among vertebrate animals. Progressing by alternate contractions of its lateral muscles, and opening its jaws to take in food and water, the Fish adds to these little else but those undulations of the fins and tail that serve to balance and turn it. A Reptile, using its limbs in the water or on land or both, performs muscular actions considerably more varied and more combined; but still, actions that are directed to comparatively few ends. An ordinary Mammal exhibits in the chase and destruction of prey, in the making of burrows, in the rearing of young, in the laying up of food, a greater variety of actions that are severally more compound. On arriving at the higher Mammals, ending with Man, we meet with motions that are almost countless in their kinds, that are severally composed of many minor

motions accurately adjusted in their relative quantities and successions, and that are themselves compounded into courses of action directed to multiform objects. And with each such increment of complexity in the motor functions throughout the *Vertebrata*, there goes an increment of nervous endowment.

This, then, is the secondary connection which traverses and complicates the primary connection. We saw that were there no other relation than that between quantity of nerve-tissue and quantity of motion generated, a Horse should have a far larger nervous system than a Man, instead of having a smaller one. But finding that there is also a relation between quantity of nerve-tissue and complexity of motion, we are led to expect an exceptionally large nervous system in Man; and are enabled to understand why he has a larger one than a Horse has. More obvious, because not involved with irrelevant differences, is the interpretation thus yielded of the general rule, already illustrated in the case of the Dogs, that in each natural group or order of Mammals, the nervous systems do not increase in the same ratio as the bodies. We will glance at another illustration of this, supplied by the *Primates*: specially instructive because of the significant exception it contains, and specially interesting because that exception is furnished by mankind.

The small monkeys have relatively very large brains—larger relatively than the brains of their congeners, including even the highest. This connection, parallel to that presented in the spaniel and the newfoundland, has a parallel explanation. The movements of the little Capuchin monkey are approximately as varied and complex as those of the great Gorilla; and hence, in so far as nervous evolution is related to heterogeneity of motion, the Capuchin should have a nervous system differing but little in size from that of the Gorilla. But since there is also a relation between quantity of nerve and quantity of motion generated, the Gorilla's

nervous system must be absolutely greater though relatively smaller: which we find it to be. Between the Gorilla and Man, however, there exists a converse contrast. Heavier than a Man, and moving about in the trees, a Gorilla probably generates daily as much motion as a savage, or as a civilized labourer; and were it the sole function of nerve-tissue to originate motion, should have at least as large a nervous system. But the nervous system of Man is twice as heavy. Here, therefore, all other relations being substantially the same, and the physiological processes being approximately alike in the two cases, the relative largeness of the human nervous system stands clearly related to the relatively-enormous complexity of human actions—a complexity shown partly in the more compound simultaneous movements, but mainly in the combination of successive movements, simple and compound, directed to remote ends.

§ 6. This double relation must still be taken as approximate only. Seeing as we did at the outset that the genesis of motion depends on many physiological conditions, of which each is separately variable, it is manifest that the fundamental connections we have traced must have sundry minor irregularities. Without treating of these in detail, it may be well to instance one—that due to difference of bodily temperature. Birds as a class are more active than Mammals as a class; and though many Mammals go through motions more heterogeneous than those of Birds, yet the inferior Mammals can scarcely be said to exceed Birds in the heterogeneity of their motions. Nevertheless, the nervous systems of Birds are relatively somewhat smaller than the nervous systems of Mammals. The explanation is that Birds have a higher blood-heat with its accompanying more active respiration—both implying a greater rate of molecular change. And a greater rate of molecular change enables a smaller nervous system to generate an

amount of motion which would require a larger nervous system if the rate of molecular change were less.

A further qualifying fact to be here named is that, all other things being equal, the power of a nervous system does not vary exactly as its mass. For reasons that will hereafter appear, its efficiency as a motor agent increases in a somewhat higher ratio than the quantity of matter it contains.

But after all modifying causes have been allowed for, there remain substantially intact the fundamental relations set forth—namely, that wherever much motion is evolved, a relatively-large nervous system exists; that wherever the motion evolved though not great in quantity is heterogeneous in kind, a relatively-large nervous system exists; and that wherever the evolved motion is both great in quantity and heterogeneous in kind, the largest nervous systems exist.

§ 7. It is with deliberate intention that I have set out with this unfamiliar and, as many will think, somewhat strange presentation of the facts. My reasons for doing so are several.

One of them is that we are here primarily concerned with psychological phenomena as phenomena of Evolution; and, under their objective aspect, these, reduced to their lowest terms, are incidents in the continuous re-distribution of Matter and Motion. Hence the first question respecting the nervous system as studied from our point of view is—what are the leading facts it presents as expressed in terms of Matter and Motion?

Another reason is that, apart from any doctrine of Evolution, true conclusions respecting psychical phenomena must be based on the facts exhibited throughout organic nature; and that the above statement does literally nothing else than express these facts—expresses, too, all that direct induction can tell us respecting their essential relations.

The actions of all organic beings, including those of our own species, are known to us only as motions. Shutting out our inferential interpretations, the leaps and doublings of the escaping prey in common with the variously-adapted and rapidly-changed actions of the pursuer, are, to our perceptions, nothing but movements combined in particular ways; and so too are the changes of expression, tones of voice, and verbal articulations of our fellow-beings, on which we put such hidden implications. As, then, science requires us to distinguish the facts as actually presented from the suppositions we ordinarily join with them, it is needful to exhibit, in all its nakedness, this primordial relation between the external motions and their internal originator.

Yet a further reason for setting out thus, is that we so escape from pre-conceptions. Those who bring with them to the investigation of psychical phenomena, the hypotheses that have descended to us from the past, are almost sure to be more or less biassed thereby. While intending to avoid assumptions they are in great danger of having their conclusions vitiated, if not by some ancient or mediæval idea under its overt form, yet by corollaries from it that have unobtrusively embodied themselves in unsuspected postulates. As we shall presently see, even physiologists have been in some cases thus misled.

Hence, then, without at all calling in question the truth of those other and quite different interpretations of nervous phenomena that are tacitly expressed in ordinary language, it is proper for us here to ignore them. Before studying the facts from a psychological point of view, we have first to study them from a physiological point of view. The primary truth disclosed by the facts as so studied, is the universality of this relation between the degree of nervous evolution and the quantity and heterogeneity of the produced motion. We now pass to the secondary truths similarly disclosed.

CHAPTER II.

THE STRUCTURE OF THE NERVOUS SYSTEM.

§ 8. An outline of nervous structure must precede a detailed account of it; and the essential facts to be indicated in an outline may be brought most clearly into view by comparing with one another the nervous systems possessed by different types, and by different grades of the same type. We will limit our comparisons to the three superior sub-kingdoms of animals.

A minute nodule with diverging threads constitutes the rudimentary nervous system, as existing in the lowest Mollusk. In the Lamellibranchs several such minute nodules, or ganglia, are distributed, usually in pairs, in different parts of the body; and beyond the free fibres which they severally give off to neighbouring organs, there are fibres by which they are connected together. Gastero-pods, considerably higher in organization and activity, have nervous centres among which a considerable heterogeneity is produced by the greater size of some than of others. And besides a local integration of paired ganglia into single bi-lobed ganglia, there is an advance in general integration, shown by a clustering of the more important ganglia about the head. The Cephalopods, and especially the dibranchiate division of them, in which the molluscous type reaches its highest, show us, carried still further, that integration of the nervous system due to simple growth, joined with that

integration due to concentration and coalescence of independent centres; and they also show us the differentiations involved by their changes of size, form, and distribution.

A delicate cord running from end to end of the body, and giving off lateral fibres in pairs, constitutes the nervous system in the lower *Annulosa*. When from limbless Annelids we pass to the Articulate types, composed of segments bearing limbs, we find the nervous system formed of a series of centres, each sending fibres to the different organs of its own segment, and all of them united by a thick cord of fibres with a fused cluster of similar centres in the head. In the higher *Articulata* there is an increased relative size of the nervous centres as compared with their connecting structures; an actual approach of the chief nervous centres to one another, both longitudinally and laterally; and a final coalescence of them. This integration disclosed by comparisons of lower and higher types, may also be observed in progress during the development of the individual insect or the individual crustacean. And along with advancing growth, consolidation, and combination of nervous structures, there may be traced an increasing unlikeness, both among the central masses themselves, among their connecting cords, and among their divergent fibres.

Such traits of evolution are exhibited under another form in the vertebrate sub-kingdom. Its lowest known member, the *Amphioxus*, has a simple cranio-spinal axis, the anterior extremity of which is not made appreciably different from the rest by development of distinct cerebral ganglia, and which gives off lateral nerves that have but minor dissimilarities. The cyclostome Fishes, possessed of cerebral ganglia that are tolerably manifest, lead us to the ordinary fishes, in which these ganglia, individually much larger, form a cluster of masses, or rudimentary brain. Here, however, though in contact, they preserve a serial arrangement: their aggregation is little more than

that of close linear succession. But in the highest fishes certain of them which have greatly increased, overlap the others; and tend so to form a more compact, as well as a larger, aggregate. Superior Reptiles and Birds display this relative increase of certain of the clustered ganglia, and consequent obscuration of the rest, in a greater degree. It is carried still further in the inferior Mammals. From them upwards, the leading change of nervous structure is an augmentation of the two largest pairs of these aggregated nervous centres. In Man one pair has become so enormous that the others are most of them hidden by it, and nearly merged in it. Along with this direct integration there goes on the indirect integration constituted by more intimate and multiplied connections. These are both longitudinal and transverse. While in the *Amphioxus*, the cranio-spinal axis contains but a small proportion of the nerve-fibres which, running longitudinally, serve to unite its different parts; in a superior vertebrate animal, such uniting nerve-fibres are among the chief components of the cranio-spinal axis. And, similarly, while the lateral halves of the cerebrum are but slightly connected in Birds, and have connections that are relatively deficient in the inferior Mammals, they become, in the highest Mammals, joined together by a thick mass formed of innumerable fibres. Meanwhile there have been arising differentiations no less conspicuous. Beyond that general one due to development of the anterior end of the cranio-spinal axis into cerebral ganglia; and the further one of like nature which results from the relatively-enormous growth of some of these; other differentiations have been constituted by the local unlikenesses of structure simultaneously established. As they enlarge, the greater ganglia are rendered externally dissimilar from the rest by the formation of folds or convolutions; and their internal parts severally acquire distinctive characters. The same thing holds of the peripheral nervous system. Pairs of

nerves that were originally almost uniform, are rendered multiform by the much greater growth of some than of others, and by the inner differences that accompany these outer differences.

This cursory survey of the nervous system under the various forms it presents throughout the animal kingdom, suffices to show how its evolution conforms to the laws of evolution in general. We are also shown by it what here more immediately concerns us—that while the rudimentary nervous system, consisting of a few threads and minute centres, is very much scattered, its increase of relative size and increase of complexity, go hand in hand with increased concentration and increased multiplicity and variety of connections. Carrying with us this general conception, let us now study its structure more closely: considering, at first, not any particular forms of it but its universal form.

§ 9. The nervous system is composed of two tissues, which both differ considerably from those composing the rest of the organism. They are usually distinguished from one another by their colours as grey and white, and by their minute structures as vesicular and fibrous. Chemical analyses have not at present thrown more than a flickering light on the constitution of nerve-matter in general, or on the constitution of one kind of nerve-matter as contrasted with the other. All that can be asserted with safety is, that each kind contains phosphatic fats and protein-substances; but that these components are both differently distributed and in different states in the two tissues. Let us see what we are told about them by the microscope, aided by chemical re-agents.

Where their evolution can be traced, the vesicles or corpuscles of the grey tissue appear to take their rise out of a nitrogenous protoplasm, full of granules and containing nuclei. Round these nuclei the protoplasm aggregates into spheroidal masses, which, becoming severally inclosed in delicate membranes (in many cases inferred rather than seen)

are so made into nerve-cells. The protein-substance, thus forming alike the chief contents of the nerve-cells and the chief part of their matrix, is, though coagulated, soft. The granules imbedded in it, both within and without the cells, consist of fatty matter. And on comparing together nerve-cells in different stages, there are seen differences in the colours of the granules, indicating a progressive metamorphosis. To complete a general idea of the grey tissue, it must be added that the more developed of these nucleated cells, or nerve-corpuscles, give off processes, usually branched, that vary in number and degree of ramification; that among the corpuscles and their branches are distributed the terminations of nerve-fibres; and that while in some nervous centres it is common for these fibres to run directly into the cells or to be continuous with certain of the processes, in other nervous centres the connections between fibres and cells are rarely if ever direct, but where they exist, are made through the remote sub-divisions of branches given off by both.

When we pass to the white or fibrous tissue, we meet with matters that at first sight appear as distinct from the others in nature as in mode of arrangement. The fibres prove to be minute tubes. Within the extremely delicate membrane of which each tube is formed, there is a medullary substance or pulp, which is viscid like oil, has a pearly lustre, and consists of albuminous and fatty substances. But unlike as the contents of the nerve-tubes and the nerve-cells thus appear to be, a careful scrutiny discloses between them an essential kinship. For imbedded in the pulp which fills the tube or sheath, there lies a delicate fibre, or "axis-cylinder," which is composed of a protein-substance. Though chemically similar to the protein-substance contained in the cells of the vesicles, this is physically different; since, besides being comparatively firm or solid, it is uniform and continuous, instead of having its continuity broken by fat granules. That this central thread of protein-substance is

the essential nerve, to which the sheath of medullary matter with its surrounding membranous sheath are but accessories, there are several proofs. One is that in the lower animals, as well as in the embryos of the higher, no medullary sheaths exist: the nerve consists of the axis-cylinder and its protecting membrane, without any pulp lying between them. Another proof is that at the peripheral terminations of nerves, even in superior animals, the medullary sheath commonly, if not always, stops short; while the central thread, covered by the outermost membrane, continues further, and ends in delicate ramifications not inclosed in distinguishable sheaths. And a further proof is that where a nerve-fibre unites with a nerve-cell, the medullary sheath ceases before arriving at the place of union; while the axis-cylinder joins the contents of the cell, and its protecting membrane becomes continuous with the cell-wall, where this exists. Hence concluding, as we are warranted in doing, that the axis-cylinder is its essential part, we see that the matter of nerve-fibre has much in common with the matter of nerve-vesicle: the differences between them appearing to be mainly that, in the nerve-vesicle, the protein-substance contains more water, is mingled with fat-granules, and forms part of an obviously unstable mass; whereas in the nerve-tube the protein-substance is denser, and is distinctly marked off from the fatty compounds that surround it: so presenting an arrangement that is relatively stable.

What is the meaning of this difference? Before seeking an answer we must remember that compound substances undergo two fundamentally different kinds of metamorphosis—one in which the components are some or all of them dissociated and distributed through surrounding space, either apart or in new combinations; and one in which the components, instead of being dissociated, are merely re-arranged, so as to alter the perceptible properties of the mass without destroying its physical continuity. The first

we call decomposition; the second isomeric transformation. These forms of change are further distinguished in this, that the one is usually accompanied by a great dissipation of motion, whereas the motion given out or taken up along with the other is relatively insignificant. There is yet a third contrast. After decomposition the separated components cannot be readily made to resume their previous relations: often it is impossible to combine them again; and in most other cases it is difficult to do this. But in many instances of isomeric transformation, resumption of the original form may be produced by a very moderate change of conditions.

Now the two kinds of molecular change thus strongly contrasted, are the two kinds of molecular change which we have reason to suspect are undergone by the two forms of nervous matter. While the protein-substance mingled with fat-granules in the vesicles, is habitually decomposed; the protein-substance forming the axes of the nerve-fibres is habitually changed from one of its isomeric states to another. Such, at least, is the assumption here made, in conformity with the conclusion drawn in the *Principles of Biology* (§ 302); where it was argued that the propagation of molecular disturbances from one place in an organism to another, tends so to modify the mingled colloidal substances as to produce, between the two places, a form of colloid that undergoes isomeric transformation when disturbed, and communicates the disturbance in undergoing the transformation; and where it was argued that this easily-transformable colloid, having had such a change set up at one end of it and passed on to the other, giving out in the process some molecular motion and consequently falling in temperature, immediately re-absorbs from the adjacent tissues permeated by blood, an amount of molecular motion equal to that which was lost: thereupon resuming its previous isomeric state, and its fitness for again propagating a wave of transformation.

Much as there is here of hypothesis, the indirect evidence

makes it probable that if this is not the true interpretation, the true interpretation is analogous to it. That the matter contained in the vesicles is the seat of destructive molecular changes, with accompanying disengagement of motion, while the matter contained in the tubes is the seat of changes which, of whatever special nature, do not involve much destructive decomposition and disengagement of motion, are beliefs for which we have several warrants;—among others, the following. The grey tissue contains far more water than the white tissue: the proportion of solids to water being about 12 per cent. in the grey tissue, while in the white tissue it is some 25 per cent. Now abundance of water facilitates molecular change, and habitually characterizes parts in which the rate of molecular change is high. Hence the implication is that the grey matter undergoes metamorphosis with much greater rapidity than the white. Stronger evidence is afforded by the fact that the grey or vesicular substance has a vascularity immensely exceeding that of the white or fibrous substance. On comparing the net-works of blood vessels that permeate the two, the difference is conspicuous; and it is much greater than at first appears. An estimate based on measurements, proves that a given bulk of the one contains about five times as many capillaries as an equal bulk of the other.* Now since these minute canals that bring and take

* The drawing on which this estimate is based, is contained in the *Manual of Human Histology*, by A. Kölliker: translated and edited by George Busk, F.R.S., and Thomas Huxley, F.R.S. The estimate is easily made. A number of equi-distant parallel lines being drawn transversely through the two net-works, the number of places at which one of these lines crosses blood-vessels within a given length (say an inch) is counted, and the like being done with an equal length of each of the other parallel lines traversing the same net-work, there is obtained, by taking an average, the number of vessels usually met with in a specified distance. The like process is then gone through with lines of the same length traversing the other net-work. These averages do not, however, truly express the comparative numbers of such intersections in the two net-works; since the meshes of the one are unlike those of the other in shape. Hence it is needful to draw an equal number of parallel longitu-

away materials, must be numerous in proportion as composition and decomposition are quick; we may infer a great difference between the rates of destructive change in the two tissues. Another contrast supports this conclusion no less strongly. The unstable granular protoplasm contained in the corpuscles, is shielded from adjacent disturbing forces by a membrane which, even where thickest, is so delicate that its existence can be demonstrated only by the help of re-agents; and which in many corpuscles cannot be made visible at all. Hence between the matter contained in these corpuscles, or vesicles, and the streams of blood that run among them so abundantly, are interposed little else than the delicate walls of the capillary blood-vessels; and thus the disturbing substances brought by each capillary, can pass with the least possible hindrance into the unstably-arranged contents of the neighbouring vesicles. Quite otherwise is it with the relations of the blood to the contents of nerve-tubes. The wall of each nerve-tube is thick enough to make it easily demonstrated; and between it and the central thread of essential matter, comes the coat of nerve-medulla. Through these barriers the disturbing agents, carried among the nerve-tubes by sparingly-distributed capillaries, cannot readily pass; and the essential nerve-thread is prevented from having molecular changes set up in it at places between its two extremes. This protection suffices so long as the disturbing agents remain normal in their amounts; but when they become excessive, as they do if the blood-vessels become congested, local changes in the nerve-threads are caused: whence one kind of neuralgia. It should be added that by

dinal lines; and to repeat with them this process of averaging. By taking the means between the resulting numbers and the previous numbers, we get a correct representation of the relative frequencies with which the vessels occur in space of one dimension. To ascertain their relative frequencies in space of three dimensions, or in solid tissue, it is of course needful simply to cube the two numbers so arrived at.

this sheathing of nerve-medulla, the essential nerve-threads, besides being shielded against disturbances from neighbouring currents of blood, are shielded against disturbances from nerve-threads in the same bundle. Were "axis-cylinders" lying in lateral contact not thus coated, a molecular change propagated through one would set up molecular changes in its neighbours; as, in fact, it does in an early stage of ataxy, characterized by loss of the medullary sheaths. Hence, too, the explanation of that normal absence of medullary sheaths which sundry nervous structures show us. For among the *Invertebrata*, in which this normal absence occurs, the fibres contained in the same bundle have nothing like those many and varied distinctions which they have in the higher animals: they have termini of which the structures and functions are much less differentiated. Similarly with those bundles of grey or non-medullated fibres, contained in the sympathetic system of vertebrate animals; for these bundles, serving to establish relations among the viscera, each of which is much less divided into parts that act independently, there needs no such perfect insulation of the nerve-fibres. And the like holds even in certain portions of the peripheral cerebro-spinal system; as the olfactory expansion, which consists of an extensive plexus of non-medullated fibres, and which has the peculiarity that different parts of its area are not acted upon separately.

The evidences, direct and indirect, thus justify us in concluding that the nervous system consists of one kind of matter under different forms and conditions. In the grey tissue this matter exists in masses containing corpuscles, which are soft and have granules dispersed through them, and which, besides being thus unstably composed, are placed so as to be liable to disturbance in the greatest possible degree. In the white tissue this matter is collected together in extremely slender threads, that are denser, that are uniform in texture, and that are shielded in an unusual

manner from disturbing forces, except at their two extremities. And the implication on which we henceforth proceed is, that the masses, unstably constituted and conditioned, are seats of destructive molecular changes, and disengagement of motion; while the stably constituted and conditioned threads, are the seats of molecular changes that are not destructive, and are probably isomeric.

§ 10. Nerve-tubes with their contained protein-threads, and nerve-cells with their contained and surrounding masses of changing protein-substance, are the histologic elements of which the nervous system is built up; and we have now to ask in what way they are put together. We will begin with the peripheral terminations of the nerve-tubes; or rather, with those of them which lie on the outer surface.

Suppose the skin, including those introverted portions of it which form the receptive areas of the special senses, to be marked all over in such a way as to form a net-work. Suppose the meshes of this net-work to vary extremely in their sizes; so that while in some places they are as large as those of a fishing-net, they are in other places not large enough to admit the point of a needle. Or, to speak specifically, suppose that on the middle of the back the meshes are some $2\frac{1}{2}$ inches in diameter, and that being equally large over the middles of the fore-arms, and the middles of the thighs, they diminish to 2 inches and less over the neck and breast, to $1\frac{1}{2}$ inches at the extremities of the legs, to $1\frac{1}{4}$ inches on the backs of the hands, to less than an inch on the forehead, to less than half-an-inch over the cheeks and over the palms of the hands, to a quarter of an inch and less over the fingers, to a twelfth of an inch at the inner tips of the fingers, and at the tip of the tongue to one twenty-fourth of an inch in diameter; and suppose, further, that over the back of that dermal sac which forms the eye, these meshes are so small that a microscope

is required to distinguish them. Having imagined such a net-work of which the meshes, irregularly polygonal in their outlines, are thus wide over parts of the surface that have but little variety of converse with the external world, and become smaller in proportion as the surfaces have multiplied and variable contacts with things; we shall have gained an approximate idea of the relations among the separate local areas in which there arise independent nerves. To complete the conception, however, something else must be supposed. The large meshes we must represent as marked out by very broad lines—say a quarter of an inch broad where the meshes are largest. We must imagine them narrowing as the meshes become smaller; until, when we come to the meshes over the surface of the retina, the dividing lines have dwindled to the thickness of a gossamer thread. And now let us conceive that within each of these areas, large or small as it may happen, there exists a plexus of fibres, formed of the essential nerve substance, that are continuous with one another, but have no connection with the fibres occupying adjacent areas. Not, indeed, that we must conceive any sharp limitation of the space occupied by each plexus. We must assume that the line separating two areas, here very broad and here very narrow, covers a space into which fibres from both the areas run, without joining one another. Hence the area belonging to each independent plexus, is the internal area of the mesh, plus the space occupied by its circumscribing broad or narrow line; and the breadth of the line represents the extent to which adjacent areas overlap. Such, then, are the peripheral expansions of those nerves which are liable to be acted on by external forces. Here each monopolizes a relatively-great tract of the surface, and here an extremely minute one. Each is an independent agent—each is capable of having a change set up in it without changes being set up in its neighbours. The skin is, as it were, occupied all over with separate feelers, that are here

widely scattered, here clustered, and here crowded together as closely as maintenance of their individualities will allow.

From the nerve-plexus occupying one of these areas, there takes its rise the central fibre, or axis-cylinder, of a nerve-tube. Coated with its medulla and inclosing sheath, it takes its way from the surface inwards, and, proceeding without any branch or junction, eventually reaches a mass of grey matter with imbedded vesicles—a nerve-centre or ganglion. Into the substance of this the essential nerve-thread runs, becoming divested of its medullary sheath; and where the structure is least involved, the essential nerve-fibre frequently if not always ends in a nerve-vesicle. In such simple, and what we may call typical, centres, there branches out from some other part of the nerve-vesicle, another nerve-fibre which, similarly inclosed in its double sheath, pursues an outward course, ordinarily along the same general route as the first, until, reaching the same part of the body, it buries itself in a bundle of muscular fibres amid which its ramifications end. Thus we have as the elements of what is called a nervous arc—1, a peripheral expansion, placed where it is liable to be disturbed by an external agent, and so formed as to be most easily disturbed; 2, a connected fibre capable of being readily affected by disturbances at this outer end, but shielded from disturbances elsewhere; 3, at, or near, the inner end of this fibre, a corpuscle of unstably-arranged substance, apt to give out much molecular motion when disturbed; 4, a second fibre diverging from the corpuscle, or its neighbourhood, and subject to disturbance from the molecular motion disengaged near its origin, but protected from other influences; 5, at the remote extremity of this second fibre, a subdivided termination amid a substance that contracts greatly when disturbed, and which, in contracting, moves the part of the body in which the first fibre took its rise. Fig. 1 is a diagram representing these elements of a nervous arc: A being the first, or, as it is called, afferent nerve,

with its peripheral expansion *a*; B being the nerve-corpuscle or ganglion-cell; and C the second, or efferent, nerve, with its termination *c*.

Fig. 1.

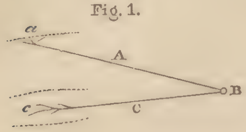
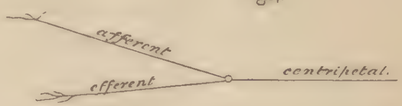


Fig. 2.



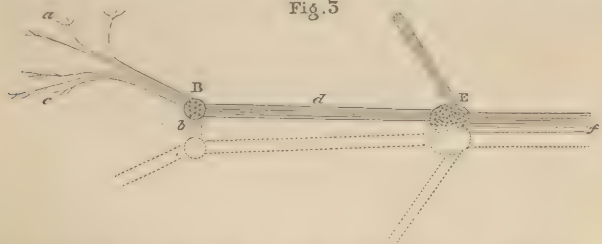
This arrangement of parts is perpetually repeated throughout the nervous system; and if we generalize the conception somewhat by supposing that the commencement *a* is not necessarily external, but may be on an inner surface, or within an organ, while the termination *c* is not necessarily in a muscle but may be in a gland; we shall have a conception that is, in a certain sense, universally applicable. I say in a certain sense, because, until another element is added, the conception is incomplete. These coupled nerves, with the ganglion-cell acting as a direct or indirect link between them, recurring everywhere in substantially the same relations, appear to form a compound structure out of which the nervous system is built—its unit of composition. But this is not so. By multiplication of such arcs we may get a multitude of separate nervous agencies, but not a nervous system. To produce a nervous system there needs an element connecting each such nervous arc with the rest—there needs a third fibre running from the ganglion-cell, or its neighbourhood, to some place where other communicating fibres come; and where, by direct or indirect junctions, actual or approximate, the primary couples of nerves may be brought into relation. That is, there requires what we may call a *centripetal* nerve.* In

* The words *centripetal* and *centrifugal* are occasionally used in nerve-physiology as the equivalents of afferent and efferent. But as afferent and efferent are by far the most generally adopted, and are also the most descriptive, it seems to me that the word *centripetal* may with advantage have this more special meaning given to it; and *centrifugal* the correlative meaning.

Fig. 2 is shown, diagrammatically, the relation in which this stands to the others. A centripetal nerve being added, there results what we may fairly regard as the unit of composition of the nervous system. We shall have presently to recognize certain fibres which this conception does not include. But they are not essential; for a nervous system is possible without them. Let us, then, taking this as our unit of composition, consider the general method after which a nervous system is constructed.

§ 11. The fibres represented in the above diagrams, do not ordinarily pursue their respective courses by themselves: they proceed in company, as shown in Fig. 3. The afferent nerves arising at *a*, in separate but adjacent areas on the skin, or in other organs recipient of external impressions, converge; and, while maintaining their separate individualities, become united into a bundle inclosed in a sheath.

Fig. 3



Other sheathed bundles of fibres from other clustered areas in the same region, presently join them, and run along with them in a compound bundle, until they eventually reach the mass of imbedded nerve-vesicles constituting a ganglion or nervous centre B. Similarly the efferent nerves which have their roots in this ganglion, issue from it as a bundle, which, commonly inclosed in the same general sheath as the afferent nerves, goes back to the part of the body whence these arose; and secondary bundles of these efferent nerves, diverging and re-diverging from one another as they enter this part, as at *c*, finally become lost in its various muscles.

In like manner the centripetal fibres *d*, originating in this ganglion, take their common course, joined perhaps by other fibres originating elsewhere, towards a ganglion E, that is larger and has more numerous connections. Of course the clustered lines and spotted circles in Fig. 3, are entirely diagrammatic—give no idea of the separate nerves and bundles and ganglia as they actually exist; but merely of the relations in which they stand to one another. It should be added that the more central ganglion, to which converge other bundles of centripetal nerves (together with some afferent nerves that pass through inferior ganglia without stopping) may itself be subordinate to a still superior, or still more central, ganglion. To this it gives off what may be called superior centripetal nerves; and other nerves of the same or of a lower order being brought to it, this highest ganglion becomes a place where there are established communications among all the subordinate and sub-subordinate ganglia, with their afferent and efferent fibres.

One further kind of connection exists. The immense majority of animals, have their parts symmetrically arranged—sometimes radially but more frequently bi-laterally. For the corresponding parts there are habitually corresponding ganglia; and the connections that remain to be named are those between these corresponding ganglia, or ganglia which belong to the same grade. Such connections consist of what are called commissural fibres. They are indicated at *b*, where they transversely join the structure shown in detail, with the answering structure belonging to the other side of the body. The word commissural is, indeed, sometimes used in a wider sense: including fibres that unite ganglia of different grades. But since the great majority of the fibres called commissural are those which join duplicate ganglia, or else ganglia that occupy like relations in the hierarchy, it will, I think, conduce to clearness to restrict its application to these: leaving the word centripetal for fibres which connect ganglia of lower orders with those of higher orders.

The commissures thus bringing into relation the members of each pair of centres, inferior or superior, and so linking the two halves of the nervous system, complete the nervous communications throughout the organism.

This description, purposely generalized with a view of exhibiting the principles of nervous organization, apart from any particular type, may be fitly supplemented by the description of a special structure that illustrates them. Each sucker on any arm of a cuttle-fish, has a ganglion seated beneath it. To this descend the afferent nerves that are affected by touching the sucker; and from it ascend the efferent nerves distributed to the muscular fibres of the sucker. These form a local nervous system that is experimentally proved to have a certain completeness in itself. But now from the ganglion underneath each sucker, fibres run along the arm, in company with fibres from all similar ganglia in the arm; and this bundle of centripetal fibres eventually reaches a ganglion at the base of the arm. Each arm, similarly constructed, thus has a chief nervous centre in which the fibres from all its minor nervous centres are brought into communication. Further, all round the ring formed by the united base of the arms, there runs an annular commissure connecting these superior ganglia. And then from each of them is given off a bundle of fibres that proceed centripetally to a still higher centre—the cephalic ganglion; where, consequently, nerves from all the arms are brought into direct communication with one another, and also into communication with nerves arriving from ganglia in other parts of the body. Omitting details and qualifications, not essential to such a conception as concerns us here, we thus see that in nervous structure there is a centralization and re-centralization, that is carried far in proportion as the organization is high.

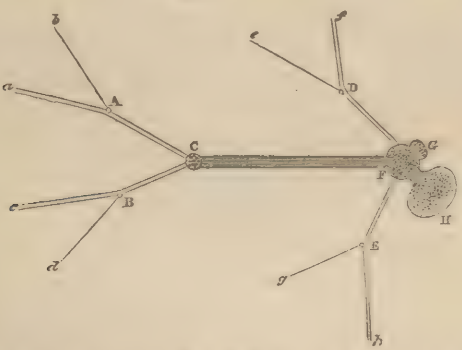
§ 12. We may be sure that along with a principle of arrangement among connecting structures, there goes some

principle of composition in the centres that are connected; which are not simply places for the meeting of fibres, but places in which there exist agents liable to be acted on by the in-coming fibres and capable of acting on the out-going fibres. Respecting the principle of composition, our reasonings must be mainly hypothetical; but they will, I think, prove of some worth, by leading us to conclusions that harmonize with observation, so far as this carries us.

In ascending from the lowest to the highest types of the nervous system, we see that the distribution and combination of nerve-fibres are so modified, as to make possible an increasing multiplicity, variety, and complexity of relations among different parts of the organism. What kind of modification does this necessitate at places where the nerve-fibres are put in communication? Without assuming that two fibres which bring two parts of the organism into relation, are always united at their central extremities by an intermediate nerve-corpuscle, it may be safely assumed that continuity between their central extremities must be effected either by a nerve-corpuscle or by some less-defined portion of grey substance; and it is clear that in proportion to the number of different connections to be established among the nerves coming to any ganglion, must be the number of the more or less independent portions of grey substance required to establish them. Let us consider the implications. Suppose that *a* and *b*, Fig. 4, are two points in the organism. To join the nerves proceeding from them, there needs only the single ganglion-cell A. Similarly, to bring into nervous relation the points *c* and *d*, the single ganglion-cell B suffices. So long as A and B remain unconnected, these two simple relations are the only possible ones among the points *a*, *b*, *c*, *d*. But now assume that from A and B there run fibres to the centre C—not a single fibre from each, but two fibres, one of which in each case proceeds from a or *b*, and from *c* or *d*. This being so, there may be formed at C, eleven simple and compound relations: these four

points can be arranged into six groups of two, *a b*, *a c*, *a d*, *b c*, *b d*, *c d*; into four groups of three, *b a c*, *b a d*, *a c d*, *c b d*; and into one group of four, *a b c d*. Hence, supposing the centre C to be made up of the independent cells, or portions of grey substance, severally serving to link the members of a group into a separate combination, there must be at least eleven such. If, again, from this centre C, we assume that there run adequately numerous fibres to the higher centre F, and that this is also duly connected through the centres D and E, with the points *e*, *f*, *g*, *h*; then the possible number of groups, simple and compound, that may be formed at F, will amount to 247; and to unite the members of each group so that it may be independent of the rest, there must be at least 247 connect-

Fig. 4.



ing links at the centre F. Without pursuing the calculation, it will be manifest that as these points in the organism increase in number, and as the clusters of them that are to be brought into relation become larger and more various, the central elements through which their relations are established must grow multitudinous. An inadequate conception, however, is thus reached; for we have considered only the requisites for forming among these points, the greatest *number* of different groups, simple and compound; ignoring the different *orders* in which the

members of each group may be combined. Two things can be arranged in succession in only 2 different ways; three things can be arranged in 6 different ways; four things in 24 ways; five things in 120 ways; six things in 720 ways; seven things in 5,040 ways; and so on in a progression increasing with enormous rapidity. Assuming, then, that at the centre F, certain points, *a, b, c, d, e,* are to be combined, not in this succession only, but in all possible successions, there will require 120 different links of connection for this one group of five points only. These links, whether separate vesicles or less-differentiated portions of grey matter, must occupy a considerable space; and supposing they are aggregated near those pre-existing cells or links which they have to re-combine in various orders, there may result a protuberance from the centre F, as shown at G. If we suppose that instead of a group of five, a group of six is to have its members thus variously combined; or if instead of one group to be so dealt with, there are many; this lateral outgrowth may become relatively very large. And since its vesicles, or portions of grey matter, will be much more bulky than the fibres running from them to the members of groups which they combine, there may be expected to arise, as at H, a lateral centre attached to the original centre, F, by a pedicle of fibres.

Of course these diagrams and numbers are intended to convey nothing but a general idea of the principle of composition of nerve centres—not to represent any actual composition. It would be an absurd assumption that among a number of points in the body, there have to be formed as many unlike groups as are theoretically possible; and it is not to be supposed that the members of any group need ever to be combined in as many different orders as they might be combined. But while, on the one hand, the above description greatly over-states the accumulation of nerve-vesicles, or their equivalents, implied by such correlations as are actually required among a given number of points in the

organism; it immensely under-states the number of points to be so correlated, as well as the number, and variety, and complexity, of the groups into which they are to be combined. The places from which afferent nerves proceed, as well as the places to which efferent nerves proceed, are multitudinous. Very large groups of such places have their members put in simultaneous communication. The different groups so formed are innumerable. And extremely varied relations of succession are established among members of the same group; as well as among different groups. Hence we are safe in asserting that along with an increasing multiplicity and heterogeneity of nervous connections, there must go increasing massiveness of the nervous centres, or accumulations of vesicular matter.

One further corollary deserves noting. Each vesicle, or each portion of grey matter that establishes a continuity between the central termini of fibres, is not merely a connecting link: it is also a reservoir of molecular motion, which it gives out when disturbed. Hence, if the composition of nerve-centres is determined as above indicated, it follows that in proportion to the number, extensiveness, and complexity, of the relations, simultaneous and successive, that are formed among different parts of the organism, will be the quantity of molecular motion which the nerve-centres are capable of disengaging.

§ 13. As a datum for Psychology of the most general kind, the foregoing description of nervous structure might suffice. But having to deal chiefly with that more special Psychology distinguished as human, it will be proper to add some account of the human nervous system. A few facts of moment respecting its peripheral parts, may be set down before we study its central parts.

At the surface of the body, where the extremities of nerve-fibres are so placed as to be most easily disturbed, we generally find what may be called multipliers of distur-

bances. Sundry appliances which appear to have nothing in common, have the common function of concentrating, on the ends of nerves, the actions of external agents. That this is the effect produced by the lenses of the eyes, is a familiar fact. It is a less familiar fact that certain otolites and minute rods or fibres, immersed in a liquid contained in the internal ear, serve to transform the less sensible vibrations communicated to this liquid, into the more sensible vibrations of solid masses, and to bring these directly to bear on the nerve-terminations. So, too, is it over the integument; or, at any rate, over the parts of it subject to many and varied contacts. Though men have not, like many inferior Mammals, the well-developed tactual multipliers called *vibrissæ* (known in a cat as "whiskers"), each of which is a lever that intensifies a slight touch at the outer end into a strong pressure of the imbedded end upon an adjacent nerve-fibre; yet every one of the short hairs on a man's skin acts in the same way. And then, in addition to these, there are, at places where the contacts with objects are perpetual, and where hairs do not grow, certain multipliers below the surface—small dense bodies named *corpuscula tactûs*, round each of which a nerve-fibre ramifies, and each of which, when moved by the touch of a foreign body, gives to its attached nerve-fibre a greater pressure than this would receive were the surrounding substance homogeneous: a fact which will be understood on remembering the effect of pressure on the skin when some small hard body, as a thorn, is imbedded in it.

So much for the instruments that are external to the peripheral expansions of the nerves, and serve to exaggerate the effects of incident forces. We may now contemplate these peripheral expansions themselves, as being adapted to receive these exaggerated incident forces. In the first place, the ultimate nerve-fibrillæ, ramifying where they are most exposed to disturbances, consist of nerve-protoplasm unprotected by medullary sheaths and not

even covered by membranous sheaths. In fact, they appear to consist of matter like that contained in nerve-vesicles, but without the fat-granules; and may be regarded as, like it, more unstable than the matter composing the central fibres of the fully-differentiated nerve-tubes. To this general character of the nerve-terminations, have to be added the more special characters of the terminations exposed to special forces. The delicate pale fibres which form a layer on the surface of the retina, are not directly affected by the rays of light concentrated upon them; but these rays, passing through them, fall on a layer of closely packed, but quite separate, little bodies which are the true sensitive structures; and then the minute nerve-fibrillæ that run from these to the stratum of retinal nerve-fibres, pass on their way into a layer of nerve-vesicles, with which we may presume they have connections. That is to say, this peripheral expansion of the nerve on which visual images fall, contains numerous small portions of the highly-unstable nerve-matter, ready to change, and ready to give out molecular motion in changing. It is thus, too, with those terminal ramifications of the auditory nerve, on which sonorous vibrations are concentrated. And there is an analogous peculiarity in the immensely-expanded extremity of the olfactory nerve. Here, over a large tract covered by mucous membrane, is a thick plexus of the grey unsheathed fibres; and among them are distributed both nerve-vesicles and granular grey substance, such as that out of which the vesicles arise in the nervous centres.

The significance of these structural peculiarities we shall see hereafter. For the present we need only note the distribution of them. Over the skin, which is conversant with forces of a relatively-considerable intensity—mechanical impacts, pressures, tensions,—we do not find that the nerve-terminations contain deposits of the peculiarly unstable nerve-substance. But we find such deposits where the incident forces are extremely feeble, or fall on excessively

small areas, or both. The quantity of matter which, floating as faint odour through the air, reaches the end of the olfactory nerve, is infinitesimal. Such luminiferous undulations as are allowed, during a momentary glance, to fall on one of the minute areas of the retina, are equivalent to a mechanical force inappreciable by our measures, if not inexpressible by our figures. Similarly with those atmospheric waves which, produced by the church-bell a mile away, and weakening as they spread in all directions, are conveyed to the minute otolites and rods of the inner ear, to be by them impressed on the auditory nerves. And in these places it is that we find peripheral deposits of the specially-unstable nerve-substance.

§ 14. Arising from these variously-specialized peripheral structures, the afferent nerves, collected into their bundles and compound bundles, run inwards to the spinal cord; out of which issue the corresponding bundles of efferent nerves. In one sense the spinal cord may be regarded as a continuous nervous centre; and, in another sense, as a series of partially-independent nervous centres. Each pair of trunk nerves with its segment of the spinal cord, has a certain degree of individuality; and those segments into which enter the pairs of massive nerves from the limbs, have individualities considerably pronounced; since it is experimentally proved that when severed from the rest they are not incapacitated. The tract of grey matter in the spinal cord to which the afferent nerves of a limb come, and from which the efferent nerves issue, is practically the ganglionic centre of that limb, having very much of automatic independence; and being joined by commissural fibres to a like centre belonging to the fellow limb, it forms with this an automatic pair. So that, remembering how the entire cranio-spinal axis is originally one and continuous, and that its anterior part has been differentiated and developed into quite distinct centres we may say that its posterior part, the

spinal cord, has also been so differentiated, though to a much smaller extent. To this conception two additions must be made. Beyond the internal tracts of grey or vesicular matter, and the bundles of nerve-fibres that enter into and issue from them laterally; and beyond the tranverse commissural fibres which connect the corresponding lateral portions of grey matter or partially-differentiated pairs of nervous centres; there are longitudinal commissural fibres, joining these successive pairs of nervous centres with one another, and serving to integrate the series of pairs in the same way that the members of each pair are integrated. And then, along with these fibres that unite nervous centres of the same order, there are what we found it desirable to distinguish as centripetal fibres, running from the relatively-inferior nervous centres to the relatively-superior ones; with centrifugal fibres running back.

Of these relatively-superior nervous centres, we have first to notice the *medulla oblongata;* including those parts of the *pons Varolii* which are woven into it, and similarly arise out of the fourth ventricle. This is the enlarged termination of the spinal cord, lying within the skull. Distinguished as it is from lower parts of the spinal cord by its greater massiveness, it is much more distinguished by the multiplicity and variety of its peripheral connections. While the successive segments of the spinal cord proper, have pairs of afferent and efferent nerves which are limited in their distributions to particular regions of the body; and while even such an entire group of these segments as occupy the lumbar region, have relations only with the legs and the lower part of the body; the *medulla oblongata*, by the intermediation of centripetal fibres, is brought into relation not only with the lower part of the body and its limbs, but with the upper part of the body and its limbs; and not only with these, but also with sundry of the parts which we know as the organs of the special senses; and not only with these, but also with the more important

viscera. The auditory nerves and the nerves of taste go directly into it, and though the optic nerves do not, yet from the centres to which they run there are fibres communicating with it; from its laterally-appended parts arise the nerves of the eye-muscles and the facial nerves; and the pneumogastric nerves, given off from its posterior part, put it in communication with the larynx, the lungs, the heart, the liver, and the stomach. Respecting its connections, direct and indirect, much remains to be ascertained; but what is known justifies the conclusion that the *medulla oblongata*, including the structures that are adnate, is a portion of the originally-uniform cerebro-spinal axis, which has been differentiated into a centre of a higher order than those behind it, or those at the base of the mass in front of it—higher in the sense that it has become that portion of the axis in which centripetal fibres running from the posterior ganglia, and from some, if not all, of the anterior ganglia, called by some sensory, are brought into relation with one another—a centre through which these local centres are united into one system.

Passing over with a mere recognition the anterior ganglia just named, the exact relations of which are ill-understood, but some of which comparative morphology proves to be portions of the front end of the cerebro-spinal axis that have become differentiated into ganglia of the first order, receiving those special external stimuli to which the front end of the body is exposed; there remain only to be noticed the two great bi-lobed ganglia, which in Man form the chief mass of the brain—the cerebellum and the cerebrum. Physiologists and anatomists are agreed in regarding these as centres of a still higher order. Anatomical proof of their superiority, as being the seats of still higher centralization, is very incomplete; for the difficulty of tracing the courses of all the nerve-fibres that enter into and issue from them, has hitherto been insuperable. But their connections with the subjacent minor centres and with the *medulla oblongata*,

are such as to make it certain that through the intermediation of these, they communicate with the whole peripheral nervous system; and are places in which centripetal fibres from centres of both the first and second orders, joined, possibly, with some simply afferent fibres, are brought into various relations: relations, however, that most likely differ in their natures from those established in inferior centres—differ, perhaps, as those supposed to be formed in the centre H, Fig. 4, differ from those formed in the centre F.

Among the facts of fundamental significance with which we are here concerned, one other may be named. This concerns the histological structures of nervous centres. In automatic ganglia, the direct union of nerve-fibres with nerve-cells is habitual. Throughout the spinal cord the "axis-cylinders" may not unfrequently be traced running into the vesicles. But in the higher nerve-centres direct connections are much less readily made out; and it is questionable whether in the highest they occur at all. In the grey substance of the cerebrum, the delicate nerve-fibres which, divested of medullary sheaths, run among the imbedded corpuscles, do not directly unite with them; or if it is too much to say that there are no such unions, we may say that they are rare. Such communications as exist are apparently between the branched terminations of the fibres and the ramified processes of the corpuscles. Thus at the one extreme, simple, clear, and complete connections are the rule; and at the other extreme, involved, vague, and incomplete connections.

§ 15. Some account must be given of certain remaining nervous structures, with which Psychology is indirectly concerned. Thus far we have dealt only with the fibres and centres that stand passively and actively related to the external world; but there are fibres and centres that stand related to those internal organs which make possible the continuance of relations to the external world.

The first to claim attention are the vaso-motor nerves. Bundles of these issue from the spinal cord, and, joined by bundles of nerves arising from the sympathetic system, accompany the main arteries: dividing and subdividing wherever these do, so as to supply fibres to all their branches down to the most minute. The vaso-motor nerves form, in fact, an additional series of efferent nerves. The nervous arc under its lowest form, consists of the afferent nerve with its peripheral extremity exposed to external actions, the ganglion-corpuscle to which its central extremity runs, and the efferent nerve thence issuing to end in some muscle. But as we have seen, the unit of composition of the developed nervous system, includes a centripetal fibre, running from the first or subordinate centre to a higher centre; and here we have to add, as an habitual element of this unit of composition in its complete form, a vaso-motor fibre, running to that part of the body in which the two ends of the nervous arc lie, and bringing the blood-vessels of that part into relation with the other parts of the apparatus.

The cerebro-spinal nervous system, besides having these direct communications with the muscular walls of the tubes which bring blood, both to itself and to the muscles it sends fibres to, is also put into relation with other parts on which it is equally, though less immediately, dependent—the viscera. These have, indeed, a nervous system of their own, possessing apparently a considerable degree of independence—the sympathetic system; and one all-important viscus, the heart, has a nervous system that is demonstrably independent. The morphological interpretation of the visceral nervous system is not settled; but whether it has a separate origin, or belongs to the periphery of the cerebro-spinal system, the undoubted fact is that the cerebro-spinal system, through the nerves running from it into the trunks of the sympathetic, communicates with all these vital organs; and that even the heart, complete as is its local

nervous system, is, by the vagus or pneumogastric nerve, integrated with the cerebro-spinal system.

A more particular account of these and sundry structures of the same class is not necessary here. The general fact of significance for us, is, that the brain and spinal cord which through their afferent nerves are put in relation with the actions of the external world, and which through their efferent nerves are put in relation with the structures that react on the external world, are also put in relation with the organs immediately or remotely instrumental in supplying them with nutriment, and removing the effete matters resulting from their activities.

§ 16. In the foregoing description I have endeavoured to include all that Psychology needs. Many conspicuous traits of nervous structure which some will think ought to be set down, are really altogether irrelevant. That in the spinal cord the grey matter is placed internally, while in the cerebrum it forms an outside stratum, is a fact of moment in anatomy, but one which throws no light on the science of mind. Knowledge of the truth that the posterior roots of the spinal nerves are afferent, while the anterior are efferent, is all-important to the pathologist; but to the psychologist it is quite unimportant, since this arrangement might have been reversed without the principles of nervous structure being in the least changed; and it is with these principles only that the psychologist is concerned. The leading facts embodying these principles may be summed up thus:—

The three great sub-kingdoms of animals in which the nervous system becomes considerably evolved, show us that along with the relatively-increased massiveness distinguishing the higher types of the nervous system, there goes that other kind of integration implied by increase of structural combination. There is multiplication and enlargement of the parts that unite local nervous centres with general nervous centres. Very frequently there is an approach or

clustering of nervous centres that were previously far apart. And there is both a relative and an absolute increase in those centres which have the most multiplied relations with local centres, and through them with all parts of the body.

The nervous system is made up of threads inclosed in sheaths, and corpuscles imbedded in protoplasm; of which the threads, united into bundles, constitute almost the whole of the peripheral parts, while the corpuscles with their matrix are found chiefly in the central parts. Having at its outer extremity a plexus of highly-unstable matter, a nerve-thread, consisting as we conclude of less unstable matter but matter isomerically transformed with ease, runs inwards, surrounded by substances that shield it from lateral disturbance. Eventually it reaches a mass of highly unstable matter, so conditioned as to undergo decomposition with the greatest facility; and from the place where this lies there run other like fibres to other masses of unstable matter, of the same kind, or of a different kind, or both—here to a portion of substance that contracts when disturbed, and here to a superior centre containing more of the easily-decomposed nerve-substance. These threads, afferent, efferent, and centripetal, with their connecting corpuscle or portion of grey matter, we regard as forming the unit of composition of the nervous system.

Such units are variously grouped and combined. Each local ganglion is a place where many afferent and many efferent nerves are connected by many portions of the unstable nerve-matter, capable of suddenly giving out much molecular motion. Each superior ganglion is a place where centripetal and centrifugal fibres from such local or inferior ganglia, are similarly connected by similar matter. And so with still higher ganglia in their relations to these. From which principle of combination it results that the possibilities of different compound relations increase as fast as the centralization progresses.

We saw, however, that this establishment of more

numerous, more involved, and more varied relations among the parts of the organism, implies not simply this grouping of fibres and this arrangement of centres; but also a multiplication of the nerve-corpuscles, or portions of grey matter, occupying their centres. And we found it to follow that where the compound relations formed are among many points, or where the points are to be combined in many orders, or both, great accumulations of grey matter are needed: an important corollary being that the quantity of this matter capable of giving out much motion, increases in proportion as the combinations formed become large and heterogeneous.

Passing to the special nervous structure related to that special Psychology of chief importance to us, we saw that the spinal cord is a series of partly dependent, partly independent, double nerve-centres; each concerned with a particular portion of the trunk or a particular limb, to the skin, muscles, and vessels of which it sends nerves. The enlarged cephalic extremity of the spinal cord, the *medulla oblongata*, is a centre connected by centripetal fibres with these partially-differentiated inferior centres; and receiving, as it also does, directly or indirectly, nerves from the special sense-organs, the *medulla oblongata* is a centre where the local centres concerned with nearly all parts of the body, are brought into communication. We saw, lastly, that the two great bi-lobed masses overlying the *medulla oblongata* and the sensory ganglia, with which they are intimately connected, may be regarded as centres in which these compound connections are united into connections still more compound, still more various, and still more numerous.

One further fact which it remained for us to note, was that while the more important nervous structures are those which bring the parts that are acted upon by the outer world, into relation with the parts that react upon it, there are also nervous structures that bring all these into relation with the vital organs: so serving to unite the parts which expend, with the parts which accumulate and distribute.

CHAPTER III.

THE FUNCTIONS OF THE NERVOUS SYSTEM.

§ 17. When, at the outset, we inquired what are the manifestations with which the nervous system is associated, we necessarily, in drawing a conclusion, asserted in general terms the part performed by the nervous system. And though in the chapter just ended the sole aim has been to describe nerve-threads, nerve-cells, nerve-trunks, nerve-centres, and the ways in which they are put together; yet the ends subserved have unavoidably, from time to time, come into view. Structure and function are in our thoughts so intimately related, that it is scarcely possible to give a rational account of the one without some tacit reference to the other. Here, however, function is to be our special topic. Having seen how the nervous system is constructed, we have now to see how it works.

The proposition with which the first chapter ended was that nervous evolution varies partly as the quantity of motion generated in the organism, and partly as the complexity of this motion. Here the initial inquiry must be, how the nervous system serves as at once the agent by which motions are liberated and the agent by which motions are co-ordinated. Three things have to be explained:—1. What are the causes which on appropriate occasions determine the nervous system to set up motion? 2. By what process

does it liberate the insensible motion locked up in certain tissues, and cause its transformation into sensible motion? 3. How does it adjust sensible motions into those combinations, simultaneous and successive, needful for efficient action on the external world? These questions cover the whole of its functions; or, at any rate, all those of its functions with which we are directly concerned. We have to interpret its passive function as a receiver of disturbances that set it going; its active function as a liberator of motion; and its active function as a distributor or apportioner of the motion liberated.

Probably it will be thought that there is here introduced a function distinct from those before named. It seems that the receiving of disturbances, or stimuli, can be included neither under the head of disengaging motions nor under the head of co-ordinating motions. But on reducing the facts to their lowest terms, and to those terms which Physiology proper can alone recognize, the difficulty disappears. For all nervous stimuli are motions, molar or molecular; and the function of co-ordinating motions comprehends not simply the combining and apportioning of the motions expended, but also the combining of the motions received, and the adjustment of the one set into harmony with the other. A moment's thought justifies this proposition. The stimuli to the nerves of touch are sensible motions of the imbedding tissue, caused either by the impacts of external moving bodies or by motions of the organism which bring it against external bodies, fixed and moving. The auditory nerve receives the motions conveyed to it from masses of matter that are vibrating. Those minute agents that terminate the nerves of the retina are acted on by luminiferous undulations—motions of the ethereal medium which produce motions among their molecules. So, too, the nerves excited by sapid and odorous substances, are, in fact, excited by the molecular movements these substances cause in their extremities by chemically changing them. Thus, speaking not

figuratively but literally, an afferent fibre of whatever kind is a recipient of motion given to its molecules: either by molar motion, as when a blow is received; or by the motion of other molecules, as when there is contact with a chemically-active body; or by those ethereal molecular motions which constitute radiant heat and light.

It will be well to consider more fully this sub-division of nervous functions, and the reasons for here proceeding upon it.

§ 18. Physiology is an objective science; and is limited to such data as can be reached by observations made on sensible objects. It cannot, therefore, properly appropriate subjective data; or data wholly inaccessible to external observations. Without questioning the truth of the assumed correlation between the changes which, physically considered, are disturbances of nerves, and those which, psychically considered, are feelings; it may be safely affirmed that Physiology, which is an interpretation of the physical processes that go on in organisms, in terms known to physical science, ceases to be Physiology when it imports into its interpretations a psychical factor—a factor which no physical research whatever can disclose, or identify, or get the remotest glimpse of. The relations between nerve-actions and mental states form a distinct subject, to be dealt with presently. Here we are treating of nerve-actions on their physiological side, and must ignore their psychological side.

Doing this, we have no alternative but to formulate them in terms of motion. And having recognized the primary division to be that between the liberation of motions and the co-ordination of motions, we find that this last division must be sub-divided. It includes, first, the co-ordination of the motions received with one another; and, second, the co-ordination of the motions expended with the motions received, and with one another. Hence results a generalized

idea of nervous functions, as divisible into *recipio-motor*, *libero-motor*, and *dirigo-motor*.

It must be admitted that in their higher forms, these functions are so entangled that a tripartite division of them is difficult, if not impossible. To the simplest types of nervous structure, the classification is easily applied: each afferent nerve is a *recipio-motor* agent; each ganglion is a *libero-motor* agent; each afferent nerve is a *dirigo-motor* agent. But in complex nervous systems, formed of inferior and superior centres connected by parts containing nerves that are centripetal, centrifugal, and commissural, there arise corresponding secondary functions which greatly obscure the primary functions. It remains true that all the afferent nerves are receivers of motions, and that all the efferent nerves are directors of motions; and it remains true that the vesicles and portions of grey substance throughout the centres are liberators of motions; but of the fibres largely composing these centres we must say that their functions are both receptive and directive. Nevertheless, we shall be considerably helped by thinking of the afferent nerves as *recipio-motor* and the efferent nerves as *dirigo-motor*; while we think of the nervous centres as composed of *libero-motor* elements along with elements that perform both the other functions.

This general conception has now to be made specific. In dealing with functions we will follow the same order as we did in dealing with structures—we will consider first the offices of the different kinds of nervous matter.

§ 19. The grey substance and the white substance—or, to speak more strictly, the nitrogenous matter in and around the vesicles and the nitrogenous matter occupying the centres of the nerve tubes—have not absolutely distinct duties. Certain simple animals yield evidence that in the rudimentary nervous system, there is no such structural differentiation and consequently no such functional differ-

entiation; and there is proof that even in the highest animals the differentiation is incomplete.

On the one hand the vesicular substance, having for its chief office to give out molecular motion when disturbed, has also a considerable power of conveying or conducting molecular motion. When the fibrous parts of the spinal cord have been cut, it is found that if the central columns of grey matter remain uncut, or if there remains even a narrow link to maintain the continuity of the grey matter, disturbance is still communicated through it to the brain: not, indeed, disturbance of any special kind, but disturbance of the most general kind. True, it does not follow that such disturbance passes along the grey matter from end to end. Throughout the whole length of the spinal cord, nerve-fibres divested of their medullary sheaths enter into and afterwards issue from the grey matter; and, again protected by their sheaths, proceed upwards to the brain in the surrounding white matter. Very likely these take up and convey molecular disturbances set up in the grey matter imbedding them. But even this implies that disturbances are propagated to some extent through the grey matter; and the argument requires no more.

Conversely, it is found that the matter forming the "axis-cylinder," or essential nerve-thread, can do something more than transmit molecular motion. It has a certain power of simultaneously giving out molecular motion: so sharing the property of the vesicular matter. When a nerve is irritated not far above its termination in a muscle, the effect is but small. If the irritation is at a point further removed from the muscle, the effect is greater. And the effect increases as the length of nerve through which the disturbance is conveyed increases. From this we must infer that besides the molecular motion received and transferred, there is molecular motion liberated in the nerve-fibre itself. Not that this molecular motion, like that which the vesicular matter yields up, implies an equivalent decomposition. Pro-

bably it is a concomitant of the isomeric transformation propagated through a disturbed nerve, and serving to convey the disturbance. Some such accompanying result is to be inferred, *à priori*, if the conduction is effected by isomeric transformation, or by any kind of molecular re-arrangement. When the molecules of a mass change from one form of combination to another, either absorption or liberation of motion is sure to occur. That there cannot in this case be absorption of motion is manifest; since that would involve a proportionate resistance to the transfer—the amount of force or motion received by the extremity of the nerve, would quickly be used up in transforming the adjacent part of the nerve, and the change would travel but a little way. Being thus obliged to infer that motion is liberated, we at once see whence nerve-fibre derives the power to increase the disturbance it conveys; since each portion, while passing on the wave of molecular motion, adds the molecular motion given out during its own transformation. This action may be rudely symbolized by the transfer of sensible motion along a row of bricks on end, so placed that each in falling knocks over its neighbour. For if instead of bricks which stand on tolerably broad ends and require some force to overturn them, we suppose bricks that are delicately balanced on narrow ends; and if we further suppose them so constituted that they do not dissipate motion by percussion or friction; we shall see that the motion transmitted will accumulate. Each brick, besides the motion it receives, will pass on to the next the motion which it has itself gained in falling.

The general truths to be carried with us are, that in its primordial undifferentiated state, nerve-matter unites the properties of giving out molecular motion and conveying molecular motion; but that with the advance of evolution, it becomes specialized into two kinds, of which the one, collected together in masses, has mainly the function of giving out motion, though it can still to some extent con-

duct it, while the other, collected together in threads, has mainly the function of conducting motion, though it can still to some extent give it out.

§ 20. The co-operation of these differentiated kinds of nerve-substance, having differentiated functions, is seen in its simplest form where they are combined into what was before described as the unit of composition of the nervous system. An afferent nerve, changed by a touch at its outer end, and traversed by a wave of isomeric transformation that gathers strength as it goes, communicates this wave to the comparatively large mass of unstable matter connected with its inner end. The shock of molecular disturbance, immensely increased by the decomposition set up in this unstable matter constituting a ganglion-corpuscle or its matrix, diffuses itself around, but takes mainly the shape of a relatively-powerful wave of isomeric transformation along the efferent nerve. And the efferent nerve being distributed at its other end among the fibres of a muscle, this powerful wave sets up in them an isomeric transformation of another kind, resulting in contraction (*Principles of Biology*, § 303).

The belief that these are the offices of the respective parts, is borne out by those peculiarities of structure which were described as occurring in the afferent fibres of certain special sense-organs. We saw that the outer ends of the optic nerve, the auditory nerve, and the olfactory nerve, are alike characterized by the presence of vesicular matter; and that while in this they differ from the outer ends of the nerves of touch, they also differ in being excessively sensitive. If grey matter, or the matter of vesicles, has the function of immensely multiplying any molecular motion it receives, and passing on the augmented wave of change along connected fibres, we at once have a satisfactory explanation of these peculiar peripheral structures. Take as an example the retina. One of the minute cones in its sensitive layer, measuring not $\frac{1}{10,000}$th of an inch in diameter, has its com-

ponent matter changed by the etherial vibrations emanating from a candle in a cottage-window at a great distance. The infinitesimal impact received from so faint a ray, may well be supposed insufficient to send through a considerable length of afferent nerve, an adequately-rapid wave of molecular change; but this wave, after passing through an extremely delicate fibril less than $\frac{1}{100}$ of an inch in length, comes to a layer of ganglion-corpuscles, with one of which we may presume that it unites. In this the minute disturbance sets up destructive molecular change—unlocks a considerable amount of molecular motion; and thus greatly augmented, the wave of transformation traverses the remainder of the afferent nerve without that loss of time that would result had it to gain strength by a series of increments, starting from an infinitesimal first term.

How such appliances for multiplying action co-operate in these cases where the initial action is excessively minute, may be illustrated by certain artificial appliances that co-operate in an analogous manner. A man with a hair-trigger pistol in his hand, puts its muzzle to the end of a train that runs to a powder-magazine. The slightest pressure on the trigger liberates a spring, and this drives down the hammer. Here is something like the external multiplier which, as we have seen, habitually intensifies the action that falls on the end of an afferent nerve. The propelled hammer explodes the unstable detonating powder in the cap; thus playing a part comparable to that of the concentrated pencil of light, which causes decomposition in one of the minute sensitive rods or cones of the retina. The explosion of the cap explodes the powder in the pistol: a change that may symbolize the setting up of decomposition in an adjacent ganglion-cell by a disturbed retinal element. The flash from the mouth of the pistol fires the train, which, carrying the flame onwards, blows up the magazine; and this serves to illustrate the action of the partially-decomposed ganglion-cell which pro-

pagates a shock through the afferent nerve to a large deposit of unstable matter in the optic centre, where an immense amount of molecular motion is thereupon disengaged.

The joint action of an afferent fibre, its centrally-seated ganglion-corpuscle, and the connected efferent fibre, is commonly known as a reflex action. The name indicates the general truth that the disturbance in travelling from its place of origin to the place where its effect is seen, passes through a point at which its course is bent or reflected; and in so far as it describes this very general trait the term is a good one. But if the foregoing interpretation be correct, the term is in other respects objectionable. On the one hand, it implies as essential what is non-essential. That the wave of disturbance makes a sudden turn at one part of its course, is a fact of no intrinsic moment—is merely a concomitant of the fact that the nerves it traverses have to be put in communication with other nerves, and that points of junction imply angles. On the other hand, it leaves out of sight the fact that one of these points of junction from which the wave of disturbance is said to be reflected, is a place at which it is greatly augmented; and that this augmentation of the wave is the all-important office of the matter lying at the point of junction.

§ 21. Remembering that bundles of such afferent nerves are joined to bundles of such efferent nerves, by clusters of such corpuscles imbedded in the grey matter of a ganglion, and that bundles of centripetal nerves proceed thence to higher ganglia; we have next to consider the functions of these structures as wholes.

A nervous centre, even of an inferior order, is not simply a place where afferent nerves are severally linked with their corresponding efferent nerves, by corpuscles or portions of grey matter that multiply and pass on disturbances; nor is the only further office it serves that of sending to higher ganglia, portions of these disturbances; but it is also a

place where more involved communications are effected. For in all ganglia save, perhaps, the very simplest, the corpuscles or vesicles give off processes more or less numerous, and usually more or less branched; and these branched processes, spreading through the matrix of grey matter, may be assumed to propagate in various directions, and various degrees, the disturbance set up in the corpuscle. This diffusion of liberated molecular motion has two implications. First, the number and complexity of the correlated changes produced by the original change, increase with the multiplication and variety of these processes and their connexions. And, second, along with increase in the number of correlated changes, there goes increase in the total quantity of molecular motion given out, directly or indirectly.

Fully to understand the importance of this last implication, it is needful to refer back to Fig. 4, and to the accompanying description of the way in which a nervous centre that serves to establish the various possible relations among different points in an organism, must contain a large accumulation of these connecting and multiplying links; and where it was shown how immense must become the accumulation of vesicular matter in a centre that has the office of establishing relations among these many parts in various orders. For it will be seen that as fast as the connexions become numerous and complex, so fast will enlarge the crowds of these connecting corpuscles and multipliers of disturbance which simultaneously come into action. And hence the quantity of molecular motion evolved in the nervous centres will become great in proportion as the nervous relations increase in integration and heterogeneity.

When we see how the arrangements for liberating and multiplying motion, described under their simple form in the last section, are thus compounded—when, recurring to our simile, we see how the first central magazine of force exploded, communicates with other larger magazines, and

these again with still larger, which are subsequently exploded; we shall be at no loss to understand how the slightest impression on one of the *recipio-motor* nerves, may evoke from the *libero-motor* centres a relatively-incommensurable amount of force, which, discharged along the *dirigo-motor* nerves, may generate violent muscular contractions. So that, to take a case, a slight sound may produce a convulsive start of the whole body; or an unexpected motion of some adjacent object, infinitesimal as is the modification it produces in the retina, may nevertheless cause an involuntary jump and scream.

§ 22. In treating nervous functions in general, I have unawares ended with illustrations from the nervous functions of human beings: so coming to the division of the subject on which we have next to enter. For the brief account given in the last chapter of the special nervous structures with which we are most concerned, must here be supplemented by a brief account of their special functions.

If we leave out such afferent and efferent fibres as pass through the spinal cord to and from the encephalon, and also those centripetal and centrifugal fibres which connect its various parts with the encephalon, we may regard the partly dependent and partly independent centres composing the spinal cord, as being co-ordinators of the actions performed by the skin and muscles of the trunk and limbs. A large proportion of these actions, including many of considerable complexity, the spinal cord is able to co-ordinate without aid from the higher centres; and some of the partially-differentiated centres composing the spinal cord, are able to effect simple co-ordinations without aid from the rest. We will glance at these simple co-ordinations first. If a patient paralyzed by some injury of the spinal cord that has left the lumbar enlargement intact, has his foot touched, the leg is quickly withdrawn; not only without a cerebral act, but even without his brain being in any way affected,

unless indirectly by the shaking of the bed. Thus the branched corpuscles and fibres contained at that point in the cord with which the afferent and efferent nerves of the leg are connected, have at once the function of giving out, when the disturbance is communicated to them, the requisite quantity of molecular motion, and of so directing this to the respective muscles of the leg, as to cause the appropriate movement. More involved co-ordinations are effected by the co-operation of several such centres, or portions of the grey substance, contained in adjacent parts of the spinal cord. In the human subject demonstration of this is not easy; but it is shown by experiments on inferior *Vertebrata*. A decapitated frog that has its side irritated, will bring the hind foot of that side to the spot, and move it so as to displace the irritating object. Even something further is done. If a scalpel be applied to the skin between the hind legs, these act jointly in such a manner as to push away the scalpel. The explanation is that by commissural fibres, transverse and longitudinal, the disturbances conveyed to particular centres, are communicated to sundry adjacent centres; and through their efferent nerves these direct and apportion the multiplied disturbances among a great variety of muscles. How such definite co-ordinations as these are effected by such an apparatus, we shall better understand on remembering that the relations between positions on the skin and the movements needed to bring the extremities to touch them, are tolerably constant. A frog's hind foot can reach a given point on the frog's side, only by one particular muscular adjustment; or, at any rate, by a muscular adjustment that varies within narrow limits. And since in all frogs, generation after generation, the proportions of parts, and therefore the relations of muscular adjustments to given positions, remain practically the same; it becomes comprehensible how, through the organized nervous connections that arise, a touch at any point may

cause the combined contractions needful to bring the end of the limb to that point. It should be observed here, that the conception of these acts of the spinal cord as co-ordinations of motions, is incomplete so long as the only motions contemplated are those of the muscles. Under the head of motions must be included the disturbances conveyed along the afferent nerves; for the muscular motions are so adjusted that their joint results have special relations to these received disturbances. The co-ordination is between the *recipio-motor* acts and the *dirigo-motor* acts. We may, then, regard the spinal cord as a centre of co-ordinations which, though some of them have considerable complexity, are yet relatively simple—simple, inasmuch as the disturbances received from the skin are much alike from all parts; simple, inasmuch as each muscular adjustment is mainly of a fixed or invariable kind; and simple, inasmuch as the component acts of the co-ordinated group are practically simultaneous.

That enlarged and differentiated part of the spinal cord called the *medulla oblongata*, including the root-portion of the *pons Varolii*, adnate with it and structurally so entangled that the two cannot be demarcated, we may roughly distinguish as a centre of compound co-ordination. It receives directly the auditory impressions, the impressions of taste, and, indirectly through the *corpora quadrigemina*, is affected by visual impressions: meanwhile sending impulses to the various muscles of the eyes, the face, the jaws, and the mouth. By it the movements of all four limbs are combined in joint acts; and by simultaneously regulating them, it makes the head and jaws co-operate with the limbs. The various impressions and muscular motions implied by the act of swallowing, it brings into due relation. Receiving the respiratory stimulus, it emits the stimuli to those muscles which enlarge and diminish the thoracic cavity, so causing inspiration and expiration; and, as a consequence, it is the centre which, disturbed by the more violent irritations

of the respiratory surface, sends out to the respiratory muscles those more violent impulses which cause coughing and sneezing: to which may be added, as actions belonging to the same class, crying and yawning. Lastly, through the pneumogastric nerve, it controls the action of the heart, and the actions of other viscera. Thus it is a centre to which come, in some cases directly but in most cases indirectly, impressions from all parts of the external surface, as well as from the mucous lining of the mouth, œsophagus, and lungs; and to which there also come, directly or indirectly, impressions received through the higher senses. At the same time the minor centres severally commanding groups of muscles, are by it put in relation with one another; and their respective simple actions so combined as to constitute compound actions. In short it has *recipio-motor* relations with all the parts that hold converse with the external world, while it has *dirigo-motor* relations with all the parts that react on the external world; and its function is that of adjusting the complex movements in obedience to the complex stimuli. This is not all. Being the centre which initiates and directs involved and extensive bodily actions, entailing rapid expenditure, it is the centre in which the demand for materials is indicated; and hence it becomes the regulator of the circulation, of the aeration of the blood, and of the visceral actions generally. Clearly, then, its co-ordinations are compound in comparison with those of the spinal cord—compound, because the impressions which afferent and centripetal nerves bring to it, are not only more numerous but also more heterogeneous; compound, because the impulses which it sends out are also more numerous and more heterogeneous; and compound, because it brings more involved acts into correspondence with more involved stimuli.

The functions of the two still higher centres, the *cerebellum* and the *cerebrum*, have now to be defined in terms of the same nature. How shall we express them? Both of these great bi-lobed masses arise as buds out of the

originally almost-uniform cranio-spinal axis; and as they enlarge, their distal portions grow more massive than their proximal portions, so that they end in being pedunculated. Each of them thus bears to the *medulla oblongata*, a relation like that which the superior ganglion H, in the diagrammatic Fig. 4, bears to the inferior ganglion F; and we may not unreasonably infer that their functions are analogous to those hypothetically assigned to the ganglion H. That is to say, we may regard them as organs of doubly-compound co-ordination—organs which have for their common function, the re-combining into larger groups, and into countless different orders, the already-complex impressions received by the *medulla oblongata;* and which have the further function of so arranging the already-complex motor impulses issuing from the *medulla oblongata*, as to form those far more involved aggregate actions, simultaneous and successive, which, being adjusted to these involved impressions, achieve remote ends. The general truth of this definition may, I think, be safely assumed; since it is simply a statement in other terms, of what, in ordinary language, is called intelligent action; which habitually characterizes vertebrate animals in proportion as these centres are largely developed. Thus much being granted, there arises the further question—what are the respective parts played by these two great organs in this doubly-compound co-ordination? Much difference of opinion has long existed, and still exists, respecting the particular offices of these supreme ganglia; and especially respecting the office of the *cerebellum*. Without committing myself to it as anything more than a hypothesis, I will here venture to suggest a not improbable interpretation. The common function of the two being that of co-ordinating in larger groups and in various orders, the impressions and acts co-ordinated in the lower centres, we may fitly ask—are there any fundamentally distinct kinds of order in which impressions and acts may be co-ordinated? The obvious

answer is, that there are the two fundamentally distinct orders of Co-existence and Sequence. All phenomena are presented to us either as existing simultaneously or as existing successively. If, then, these two highest nervous centres, which together perform the general function of doubly-compound co-ordination, take separate parts of this function, as, from their separateness, we must conclude that they do; we can scarcely make a more reasonable assumption than that the respective orders in which they co-ordinate compound impressions and acts, answer to the respective orders in which phenomena are conditioned. In brief, the hypothesis thus reached *à priori*, is that the *cerebellum* is an organ of doubly-compound co-ordination in *space*; while the *cerebrum* is an organ of doubly-compound co-ordination in *time*. The *à posteriori* evidence, so far as I have examined it, appears congruous, both with this view of the general function of these centres, and with this view of their respective special functions. There is complete harmony between the hypothesis and the seemingly-strange facts that these centres may be partially destroyed without causing obvious incapacity, and that they may be wholly removed without destroying the ability to co-ordinate the less complex impressions and acts. Assuming, as we may fairly do, that the cells and fibres which subserve the more involved co-ordinations, are successively added at the surfaces of these centres as they develop, it is inferable that the superficial parts may be sliced off with the least-appreciable effects on the actions; and that the effects on the actions will become conspicuous in proportion as the slices destroy the parts nearer to the lower centres: and these are the results established by experiment. Besides finding, as the hypothesis leads us to expect, that these nervous masses are relatively large in all creatures capable of adjusting their involved and continuous actions to complex and distant environing agencies; we also trace some relation between the development of each and the

peculiar capacities of the species. There is, for instance, the fact that the *cerebellum* is unusually developed in birds of prey, which have to co-ordinate with great accuracy the relations of distance, direction, and complex form, as well as very precisely to co-ordinate the involved movements appropriate to these involved impressions. And there is, on the other hand, the fact that the *cerebrum* predominates in creatures showing, like ourselves, the power of adapting, throughout long periods, concatenated compound actions to concatenated compound impressions.*

Of course this classification of the functions of the nervous centres, as co-ordinations that are simple, compound, and doubly compound, must be taken as merely approximate. No definite divisions can be made. The functions arise through increasing complications; and these general contrasts become conspicuous only when we look at the facts in their main outlines. Here, however, where the

* Let me here draw attention to papers in the *Medical Times and Gazette*, for December 14 and December 21, 1867, in which Dr. Hughlings Jackson has published some facts and inferences that quite harmonize with these interpretations, in so far as the common function of the great nervous centres is concerned.

It should be remarked that the above-proposed definitions, are, to a considerable extent, coincident with current conceptions. The *cerebrum* is generally recognized as the chief organ of mind; and mind, in its ordinary acceptation, means more especially a comparatively intricate co-ordination in *time*—the consciousness of a creature "looking before and after," and using past experiences to regulate future conduct. In like manner the function ascribed to the *cerebellum* in the foregoing paragraph, partially agrees with that which M. Flourens inferred from his experiments. It differs, however, in two respects. It implies that the *cerebellum* is not an organ for the co-ordination of motions only, or of synchronous motions only; but that it is also an organ for the co-ordination of simultaneous impressions, and for the co-ordination of the synchronous motions in adaptation to the simultaneous impressions. And it further implies that not all simultaneous impressions and adapted synchronous motions are co-ordinated by the *cerebellum*; but only the doubly-compound ones, which have for their external correlatives the intricate combinations of attributes that distinguish objects from one another, and the more multiplied and varied localizations of objects in the space that extends beyond the immediate limits and reach of the organism.

object is to give an idea of the principles of nervous function in its successive stages of evolution, detailed qualifications do not concern us.

§ 23. A few words are due to the functions of that subordinate nervous apparatus, the structure of which we glanced at in the last chapter—the nervous apparatus presiding over the vital processes. It will suffice if we take the functions of the vaso-motor division of it as exemplifying the whole.

Each vaso-motor nerve, having roots in both the cerebro-spinal system and the sympathetic system, conveys to all branches of the artery it accompanies, the impulses arising from the activities of the great nervous centres and muscles, as well as from the activities of the viscera. Probably the ordinary amount of disturbance propagated along each vaso-motor nerve, simply excites the muscular coats of the adjacent artery sufficiently to maintain its due elasticity. But stronger disturbances produce marked alterations of its calibre: those brought by the sympathetic fibres being said to cause contraction; and those brought by fibres from the cerebro-spinal system being said to cause dilatation. Some of these changes have relation to actions going on in the part itself; and others to actions going on in the chief vital organs, or in the body as a whole. But all of them show us that by means of the vaso-motor nervous system, the blood-vessels are so regulated as to subserve general and local needs. One further fact belonging to this class may be added; partly because of its intrinsic interest, and partly because it illustrates certain supplementary nervous functions not hitherto named. We have already seen that, among its many duties, the *medulla oblongata* controls, through the medium of the pneumogastric nerve, the action of the heart. So long as the disturbance conveyed to the *medulla oblongata*, either from the periphery of the nervous system or from its great

centres, does not exceed a moderate amount, the resulting waves of molecular change sent by it through the pneumogastric, do not interfere with the heart's action—perhaps enforce it. But when the *medulla* is excessively disturbed, the increased quantity of stimulus it sends, either diminishes the action of the heart, or stops it altogether: so causing arrest of the circulation and consequent insensibility. Noting, as we pass, that this is one of the most remarkable forms of that co-ordination which the nervous system everywhere effects, since the arrangement is such that when the nervous system becomes abnormally active, and its chief centres surcharged with blood, they themselves arrest the organ which propels blood to them; we have to ask how it happens that in this case the propagation of disturbance through a nerve checks action instead of causing it. The reply is that in addition to the systems of nerves which excite action, there is found to exist a system of nerves which diminish action—*inhibitory* nerves as they are called. Through these it is alleged that the brain controls the spinal cord—restraining those reflex movements which, when connection with the brain is cut off, become so much more marked. And through one of these it is concluded that the *medulla oblongata* reins in the heart, when the cerebral irritation is excessive.

Be this as it may, the facts named illustrate the way in which the nervous system, while it co-ordinates the external actions, also co-ordinates those internal actions which make them possible. The reader has but to conceive that through other systems of nerves, other organs which absorb, secrete, excrete, &c., are similarly controlled, and he will understand sufficiently for present purposes, how demand for materials and supply of materials are harmonized.

§ 24. In summing up the functions of the nervous system as thus formulated in terms of motion, it will be useful to observe the greater comprehensiveness of view we obtain by excluding the ordinary implications.

When one part of a Zoophyte is touched, the contraction set up in that part slowly diffuses itself through the whole body. Two things are here to be noted. There is a propagation of disturbance through the nerveless sarcode of which the creature is composed; for distant parts are eventually affected. There is also an increase of disturbance; for in successive moments the mass of tissue undergoing change is greater. Thus the relatively-homogeneous substance of these simple animals, exhibits the two essential phenomena exhibited by the nervous system in all phases of its development: there is propagation of molecular motion, and there is a simultaneous augmentation of this molecular motion. Such essential phenomena grow more conspicuous as the nervous system develops, partly because the changes set up become limited to narrow lines and small masses, and partly because the matter of which these are formed becomes distinguished by an increased degree of the general instability. Since, then, the functions of the nervous system as expressed in terms of molecular motion, are functions exhibited in a vague way by the undifferentiated tissue from which the nervous system insensibly arises; it is clear that by so expressing them we include alike their lowest and their highest forms, which we cannot otherwise do.

Moreover, only in these terms can there be given an adequate definition of fully-developed nervous functions. If we admit any subjective element, our definition becomes inapplicable to all those nervous actions which have no subjective accompaniments—which go on without feelings; and a conception of nervous functions which excludes those of organic life, cannot be a complete conception. On the other hand, the definition of nervous functions as consisting in the conveyance and multiplication of molecular motions, holds in all cases. It includes equally the conduction of an impression made on a nerve of sense, and the excitement of chemical metamorphoses in a gland.

The subdivision of this general function under the above-proposed heads of *recipio-motor, libero-motor,* and *dirigo-motor,* has also the advantage of greater comprehensiveness. No word at present in use expresses the office which afferent nerves have in common, more specifically than the word afferent itself expresses it. Whether disturbance of its outer end produces in an afferent nerve a change causing a reflex contraction, or whether it produces a change causing what we call a sensation, is a circumstance of secondary import; as is proved by the fact that by use the last may become the first. The essential thing common to the two, is that molecular motion is propagated from periphery to centre. So, too, is it with the *libero-motor* functions. Whether, as in the ganglia of the sympathetic, the multiplication of communicated disturbance has no subjective concomitant, or whether, as in the *cerebrum,* it has a subjective concomitant, there is in both cases a liberation of molecular motion; and this, being the common character of the changes in nerve-centres, must determine the definition of their common function. In like manner, all efferent nerves, whether conveying disturbances that set up contractions in muscles, or cause constrictions of arteries, or excite chemical transformations in glands, serve to direct the waves of molecular motion—waves that are intrinsically alike in nature, though the results produced by them in the organs to which they are carried differ so widely, and though they are now associated with consciousness and now are not.

A more special view of the functions thus classed, discloses two essential facts. Considered as an agent for generating movements, we see that the nervous system acts by liberation of successively-larger amounts of molecular motion in the centres successively disturbed. A very small change at the outer end of an afferent nerve, sets up a relatively-large quantity of change in some adjacent unstable nerve-matter; whence the change, thus increased, is propagated to some internal ganglion; to be passed on by

it immensely multiplied as before; until there is unlocked an amount of disturbance capable of causing muscular contractions throughout the whole body.

Meanwhile these centres in which molecular motion is liberated, are also the centres in which it is co-ordinated; and the successively higher and larger centres which evolve successively larger quantities of molecular motion, are also centres in which successively more complex co-ordinations are effected. Whence follows the general result that along with each further development of the nervous system, enabling it to make all parts of the body work together more efficiently in simultaneous and successive actions, there goes an increased power of evolving the energy required for such larger aggregates of actions.

These principles we found to be well exemplified in the case which most nearly concerns us. It is needless to re-state the results so recently arrived at. One remark, however, may be added. In the functions of the successively-higher vertebrate centres, reaching their climax in the human being, we see well exemplified the law of development of functions in general (*First Principles*, Part II. § 142). This progress from co-ordinations that are small and simple to those that are larger and compound, and to those that are still larger and doubly compound, is one of the best instances of that progressive integration of motions, simultaneously becoming more heterogeneous and more definite, which characterizes Evolution under all its forms.

CHAPTER IV.

THE CONDITIONS ESSENTIAL TO NERVOUS ACTION.

§ 25. Of these, the first in order is continuity of nerve-substance. Disturbance is not conveyed from end to end of a nerve that has been cut in two; and section of a nerve-centre similarly prevents the transfer of an impulse from one of the dissevered parts to the other.

The requisite continuity is not simply the continuity of unbroken contact: there must be continuity of molecular cohesion. Placing in apposition the two ends of a divided nerve, does not re-establish nervous communication. Even when, after a cut, the surrounding flesh has been healed, it is long before the sundered nerve-threads re-unite so completely that they transmit stimuli as well as before.

Further, there must be no destruction of continuity by molecular disorganization. Without division of a nerve, and without injury of its sheath, there may result from disease a change which incapacitates the nerve-fibres—an atrophy, or a breaking-up by decomposition: the result being a derangement of those lines of peculiar nitrogenous molecules which receive and pass on the waves of disturbance.

§ 26. Nerve-structures, whether peripheral or central, permanently disabled as they are by actual discontinuity, either molar or molecular, are temporarily disabled by discontinuity of molecular equilibrium. Pressure is capable of

producing re-arrangement of particles, even in substances that are simple and comparatively hard; as is shown by its power of altering the direction of diamagnetic polarity in metals. We may therefore expect that in substances of complex composition and little cohesion, pressure will readily cause the particles to change their relative positions. Hence there is no difficulty in understanding why nerve-substance, having a balanced molecular structure such that it is ever ready to pass when disturbed from one of its isomeric states to the other, may be so modified by pressure, even when small, as to be incapacitated for undergoing these alternate molecular re-arrangements. Be this as it may, however, the fact is that one of the conditions to nervous action is absence of much pressure.

In the case of nerve-trunks, demonstration of this general truth is easy. A ligature round a nerve prevents a disturbance set up at one end of it from producing any effect at the other end. Partial results of this nature are familiar. By external pressure on a limb, the conducting power of the nerves affected is much diminished.

That pressure on the centrally-seated tracts of fibres, hinders or arrests their actions, is shown in every case of paralysis. By a clot of blood that has escaped from a ruptured vessel, or by a quantity of lymph that has oozed through the walls of capillaries over-distended, bundles of fibres at the base of the brain, or in the spinal cord, are unduly squeezed; and if afferent or centripetal fibres they cease to bring disturbances from the periphery, while if efferent or centrifugal fibres they cease to convey impulses to the muscles.

The like is true of nerve-centres as wholes. Indeed pressure appears to be a greater hindrance to their actions than to the actions of nerve-trunks. That certain forms of the abnormal arrest of nervous action called coma, are due to excessive congestion of the blood-vessels of the encephalon, seems possible; but as some question this interpretation we

cannot safely base an inference on it. There is, however, one conclusive piece of evidence. A fracture of the skull that causes indentation over a considerable area, and leaves the bone intruding on the space previously filled by the brain, stops the functions of the brain—disturbances sent to it call forth no appropriate co-ordinated motions, and, indeed, no motions at all. But when, by means of a trephine, the depressed portion of bone is cut out, the brain, relieved from pressure, at once resumes its duties.

Further support is yielded by what may be regarded as converse evidence. If excess of pressure arrests nerve-action, and if the normal amount of pressure allows the normal amount of nerve-action; then it is inferable that nerve-disturbances will pass with undue facility if the pressure is deficient. Now as the brain is contained in an almost-closed chamber which cannot collapse, it follows that if the cerebral blood-vessels are rapidly drained, the masses of nerve-fibres amid which they ramify, being subject to less pressure than usual, will allow waves of molecular change to pass with unusual facility; and ordinary impressions propagated to the centres, will produce extraordinary motor impulses. Hence the seemingly-anomalous fact that great loss of blood, or great local anæmia caused by stoppage of a cerebral artery, causes convulsions. Such a result may be anticipated as the first result, before innutrition begins to tell; though innutrition will afterwards cause prostration or paralysis. And this is the order in which the phenomena actually occur. The like appears true of the peripheral nervous system. The afferent nerves of individuals who, though otherwise healthy, have lax tissues, are often unduly impressible. And there are instances of undue local impressibility which, I think, admit of this interpretation. It has been found that an arm rendered anæmic by unnatural constriction of its arteries, thereby reduced in temperature and beginning to atrophy, may nevertheless have its afferent nerves affected by electric

discharges in an unusual degree.* Deficient pressure on the nerve-trunks appears a possible cause of this otherwise strange result.

§ 27. Proof that heat kept above a certain level is a condition to the maintenance of nervous action, is difficult to disentangle from proof that the maintenance of nervous action depends on a due circulation of blood; for the one condition is usually but a concomitant of the other. Nevertheless, there is reason to infer that a supply of free molecular motion is requisite, apart from a supply of nutritive materials.

The general fact that cold-blooded animals are comparatively inactive, admits of the interpretation that their low temperature is due to their inactivity, as well as to the interpretation that their inactivity is a consequence of their low temperature; for the two act and react in such a way that neither can properly be called the cause of the other. But reptiles which remain quiescent in cold weather, and become active when they are warmed by the summer's sun, yield us good evidence. Though it may be alleged that their greater activity arises from accelerated circulation and aeration of the blood, yet as the heart and lungs are set going by their respective nervous centres, we must infer that the warming of these nervous centres by external heat, is the initial change in these animals that have but little power of producing heat by their own actions. In support of this interpretation may be cited the converse fact. When active creatures, capable under ordinary conditions of generating enough heat within themselves, are exposed to conditions under which they lose heat faster than they make it, their nervous actions decrease, and they eventually cease to move. In hybernating mammals we see

* I am indebted for this fact to Dr. Bastian, who observed it in one of his own patients.

an annual recurrence of this relation of cause and effect; and in mammals that do not hybernate, as in ourselves, it equally holds that prolonged exposure to extreme cold depresses nervous action, causing strong tendency to sleep, and that death results if the bodily temperature is allowed to fall still lower.

That local loss of heat when carried far, is followed by local inaction of the nerves, is shown by the fact that parts of the body that have been greatly cooled down, naturally or artificially, may be pricked or cut or pinched without any of the usual disturbances being conveyed to the nerve-centres. It is true that where the refrigeration is extreme, there is usually a partial deprivation of blood; but there is evidence that when this is not the case—when, indeed, the blood-vessels are congested, as in red hands on a winter's day, loss of heat entails decrease of nerve-function. That the like holds of the respective centres, is shown by the use of cold as a therapeutic agent: ice to the head being prescribed when there is excessive cerebral action, and ice to the spine being a means of diminishing reflex excitability.

It is worth remarking that this dependence of nervous action on supply of heat, yields indirect support to the views set forth in foregoing chapters. If, as was inferred, the disturbance conveyed along a nerve-thread is an isomeric change, during which some molecular motion is yielded up by each molecule as it passes on the accumulated wave to its neighbour—if resumption of the previous isomeric state implies an equivalent absorption of molecular motion from surrounding matter; then, in proportion to the heat of surrounding matter, will be the rapidity with which the nerve-fibre, resuming this previous isomeric state, becomes fit to transmit another wave of molecular change.

§ 28. That nerves and nerve-centres act only so long as they are furnished with those materials which the blood-vessels bring them, is a familiar truth. The quantity of

blood present in any part, and the rapidity with which fresh blood is propelled to the part, both affect the degree of nervous activity in the part.

General depletion is a cause of nervous inaction: if the total quantity of blood in the body is much diminished, the great nervous centres are the first organs to feel the change. Temporary loss of blood produces fainting, or sudden arrest of cerebral action; and permanent deficiency of blood is accompanied by debility, which implies a decreased nervous discharge. Supposing that no blood has been lost, insensibility nevertheless instantly results if the heart ceases to supply the brain with fresh blood in place of the blood it contains. Or if there is chronic feebleness of the heart's action, there is proportionate diminution of nervous power. Where the total quantity of blood is adequate and the heart is not in fault, local nervous function may still be hindered by local anæmia, resulting from aneurism in an artery, or from what is called an embolism—a plugging up of an artery with coagulated blood. Thus paralysis is caused by embolism of the cerebral blood-vessel which supplies the highest part of the motor tract. The converse facts similarly imply this same general relation. When, other conditions being normal, a nerve-centre is highly charged with arterial blood, it responds with unusual rapidity to the disturbances it receives; and evolves more than ordinary amounts of force, shown in secondary nervous changes, or in muscular motions, or both. Supposing, again, that there is no hyperæmia of a nervous centre, it will still happen that if the heart propels blood to it with unusual rapidity, its libero-motor function will be exalted.

At the periphery of the nervous system, like variations of efficiency follow like variations of circulation. A reduction in the quantity of blood present, caused by constriction of the vessels, is probably one cause of the decreased nervous impressibility in a part that is exposed to cold; and to the same cause is perhaps to be ascribed some of the comparative

sluggishness with which the muscles of the part respond to motor impulses. If instead of local lack of blood there is retardation or stoppage of the local current of blood, the nerves of the part similarly become incapacitated in a proportionate degree: instance the blindness that results from blocking up the central retinal artery; or instance the gradual disappearance of impressibility in a region of the skin that has had its supplying blood-vessel tied. Conversely, excess of blood around the peripheral nerve-fibres, causes unusual excitability of them. A gentle touch on the skin in its normal state, sends through the afferent nerves a disturbance so small as to call forth from the central organs scarcely any response; but where the skin is highly inflamed, a like touch affects them so much that the disturbance, when reflected from the central organs, produces a start of the whole body. If in addition to local excess in the quantity of blood there is an accelerated flow of blood, a still greater exaltation of local nervous action follows. It is a familiar truth that, other things remaining the same, an inflamed part is made more irritable by anything which increases the action of the heart.

§ 29. Nervous action depends not alone on the quantity of blood supplied but also on its quality—on the proportion of the needful elements contained by it.

General rather than special warrant must suffice for this proposition. Little is known about variations in the constitution of the blood; and still less about the relations between these and variations of nervous activity. That a blood greatly impoverished, as in dropsical persons (whose tissues become infiltrated because the thin serum passes too easily through the walls of the capillaries), is accompanied by enervation, is pretty clear; and we can scarcely be wrong in concluding that a blood rich in the constituents of nerve-substance, renders possible a great evolution of nerve-force.

But there is indirect evidence serving to enforce the scanty

direct evidence. For we have abundant proof that by adding certain matters to the blood, unusual amounts of nervous action may be evoked. Alcohol, nitrous oxide, the vegeto-alkalies, and other stimulants, are not, indeed, components of nerve-substance; nor is there any reason to suppose that they can serve in place of components. Probably their immediate influence is that of setting up or facilitating the change of nerve-substance, and so causing unusual disengagement of molecular motion. But by showing that the supply of particular substances to the nervous system exalts nervous activity, they make it more manifest that nervous activity must partly depend on the supply of substances which re-build nerve-tissue as fast as action disintegrates it.

We must not omit a further qualitative character of a positive kind. The blood must contain oxygen. What is the special action of oxygen—whether it is a direct disintegrant of the tissues, including nerve-tissue; or whether it simply facilitates by its presence molecular disintegrations otherwise caused; or whether it serves merely to combine with, and carry away, the products of such disintegrations otherwise caused; are questions about which there are differences of opinion. But there can be no difference of opinion as to the necessity for an oxygenated blood. And opinions can scarcely differ respecting the general relation that exists between the degree of oxygenation and the degree of nervous activity.

§ 30. While, for the maintenance of nervous action, it is requisite that certain matters shall be present in the blood, it is also requisite that certain other matters shall be absent; or, to speak strictly, that they shall be present in but small proportions. These are the compounds resulting from decomposition of the tissues—the nervous tissue included. The two most important are carbonic acid and urea.

If the exhalation of carbonic acid by the lungs is greatly retarded, lethargy ensues: disturbances at the periphery

of the nervous system fail to call forth the usual responses. If the exhalation is completely arrested, complete insensibility is soon produced; followed quickly by arrest of the inferior nervous functions, and consequently of all other functions. And these effects arise still more rapidly if there is an absorption of carbonic acid through the lungs, instead of an arrested excretion of the carbonic acid internally generated.

In an analogous but less rapid manner, a decrease and final stoppage of nervous action is caused by an accumulation in the blood of urea, or of those nitrogenous products represented by it. If the kidneys fail to perform their function, or if the waste nitrogenous products which they have separated from the blood are prevented from escaping out of the body, and are re-absorbed; there results a nervous inaction, ending presently in coma and finally in death.

§ 31. Such, stated as fully as is needful here, are the conditions essential to nervous action. Qualifications have been passed over; and much evidence has been omitted. In summing up these leading facts which alone concern the psychologist, we may with advantage observe how they harmonize with the general views of nerve-structure and nerve-function set forth in foregoing chapters. All these pre-requisites to nervous action obviously admit of being grouped as pre-requisites to the genesis of molecular motion, and pre-requisites to the conveyance of molecular motion.

That molecular motion may be disengaged there must be decomposition; and, therefore, for the discharge of molecular motion to be maintained, decomposition must be facilitated. The quantity of waste being a measure of the quantity of force evolved, it follows that the nervous system requires a good supply, and quick exchange, of blood; since in the blood are brought the matters that favour disintegration. Similarly with respiration, considered as a process of

absorbing that oxygen which directly or indirectly aids the metamorphosis. And so likewise with the excretion of those waste products which hinder the metamorphosis. But perpetual waste must be met by perpetual repair. If its action is to continue, nervous tissue must be re-composed as fast as it is decomposed. Hence the reason why there is needed a blood that is rich in nerve-constituents. Hence the fact that abundant blood must be present wherever there is much nervous action. And hence, also, the necessity for an efficient circulation to replace by fresh blood, the blood that has been used.

Equally well do the several conditions essential to the transmission of nervous disturbance, conform to the hypothesis that the disturbance transmitted is a wave of isomeric change. For if it is, we at once see why there must be not merely contact-continuity of nerve-fibre, but molecular continuity. We are helped to understand how pressure, by deranging that delicate molecular balance which makes possible the alternation of isomeric states, may prevent the passage of nervous discharges. And we are supplied with an explanation of the fact that the presence of free molecular motion or heat, is needful to enable a nerve continually to resume its fitness for conveying a wave of change.

Before closing the chapter it should be pointed out that these many conditions essential to nervous action, are never all fulfilled at one time in the same degree, but are usually fulfilled in various degrees and combinations; and that by now conspiring and now conflicting, they produce results that are complicated and often perplexing. Thus, for instance, substances which directly stimulate the nervous system, are usually substances which retard the exchange of gases in the lungs, and by so doing depress the state of the nervous system; and these conflicting actions, different in their proportions in different individuals, and in the same individual at different times, often work opposite effects, or work first one effect and then the other. Again,

richness of blood, by facilitating high nutrition of nerve-centres, conduces to nervous activity. Yet there is a plethoric state which is not nervously active; and starvation, with its greatly impoverished blood, has a phase at which delirium sets in, in consequence of the unduly rapid disintegration of the nerve-centres. Analogous incongruities, too numerous to specify here, continually occur. This entanglement of the conditions must be borne in mind and allowed for in each case.

CHAPTER V.

NERVOUS STIMULATION AND NERVOUS DISCHARGE.

§ 32. Every agent capable of altering the molecular state of a nerve, causes the nerve to produce the particular change which it habitually produces. Experiments prove that each nerve is made to work the same kind of effect by stimuli of all orders; or, to speak strictly, it is found that the effect is of the same kind wherever its kind renders it accessible to observation.

Thus, if an exposed end of a nerve which goes to a muscle is roughly touched, the muscle contracts. If it is eroded by an alkali or an acid, the muscle contracts. If it is galvanized, the muscle contracts. If it is suddenly heated, still the muscle contracts. Similarly with a vaso-motor nerve. No matter whether the disturbing agent be mechanical, chemical, thermal, or electric, there results at the peripheral extremity a like change in the state of the adjacent arteries.

An allied truth is that whether a nerve be irritated at the end which normally receives the disturbance, or whether it be irritated at some place between this and the organ acted upon by it, the effects wrought are alike—in nature, at least, if not in degree. As already said, the *quantity* of change set up increases with the length of the nerve through which the impulse is transmitted. But the *quality* of this

change remains identical be the stimulus applied at a near point or a remote point.

This last truth, equally with the first, harmonizes with the supposition on which we have thus far proceeded. If the disturbance that travels along a nerve is a wave of isomeric transformation, the kind of effect produced by the wave at the place it eventually reaches, will be the same whatever stimulus set it up, or wherever it commenced.

§ 33. Nerve is not capable of continuous stimulation or continuous discharge. Persistent action of whatever kind on a nerve-termination or the cut end of a nerve, does not produce a persistent effect on the connected nerve-centre, or on the connected peripheral organ.

Supposing the nerve supplying some muscle has been dissected out and cut in two; then, if the exposed part be suddenly pressed the muscle will suddenly contract; but maintenance of the pressure will not cause maintenance of the contraction. Or if this nerve is made part of an electric circuit, then, at the moment of completing the circuit, the muscle will contract; but its contraction is only momentary, and the subsequent continuance of the current works no visible effect. To keep up muscular contraction, it is requisite to send through the nerve a quick succession of separate disturbances. If the nerve forms part of an electric circuit in which there is an apparatus for breaking and completing the circuit; then, at each completion of the circuit, the muscle contracts; and when the alternate breaks and completions follow one another very rapidly, the contraction of the muscle becomes practically persistent. This truth is demonstrable by experiment on a dead frog, and also by experiment on the living human subject. A man who grasps the two metallic cylinders forming the poles of a magneto-electric machine, cannot leave hold of the cylinders when the intermittent current is passed through his arms. The like result occurs when the disturbances are mechanical

instead of electric. If the cut end of a motor nerve is subject to a rapid series of taps, the muscle it supplies is thrown into a state of tetanus.

The fact that the so-called nerve-current consists of successive pulses, is one of great significance. We shall find hereafter that it has many important corollaries. For the present it will suffice to observe how entirely congruous it is with the hypothesis on which we have thus far proceeded. If a nervous disturbance travels as a wave of molecular change—if this wave is such that the molecules of nerve-substance fall from one of their isomeric states to the other; then, having fallen in passing on and increasing the pulse or shock, they remain incapable of doing anything more until they have resumed their previous isomeric state. Hence the very nature of the process necessitates the intermittent character of nerve-action.

§ 34. The transmission of a disturbance through a nerve takes an appreciable time. The rate of transmission, as measured by Professor Helmholtz, has been found to vary from about 28 yards per second to 32 yards per second. Difference of constitution is doubtless the cause of this variation—a variation to which is due that individual peculiarity recognized by astronomers in what they call "the personal equation."

This peculiarity affords yet another confirmation of the belief that a nervous discharge is a wave of isomeric transformation. If the disturbance propagated through any series of molecules is one that does not permanently change their relative positions; then the transfer of the disturbance may be excessively rapid, because the amount of molecular momentum to be generated is excessively minute. But if the molecules have to be transposed—if, as in isomeric transformation, the components of each compound molecule have their relative positions altered; then the quantity of molecular momentum generated must be comparatively very large;

and as the genesis of this momentum takes place in each molecule before the next is affected, the transfer of the disturbance must be greatly retarded.*

* Perhaps too much has already been said respecting the nature of nerve-action. But before finally leaving the subject, I must add some important illustrative facts that have come to my knowledge while writing this chapter. They are contained in a paper by Mr. Gore, published in the *Transactions of the Royal Society* for 1858, describing the allotropic changes undergone by electro-deposited antimony. Antimony so deposited assumes, according to the conditions, two forms—a dark, amorphous, or unstable form; and a grey, crystalline, or stable form. When a mass of the amorphous antimony is disturbed at one end, there begins a change into the crystalline antimony, which spreads almost instantly throughout the whole mass, with great evolution of heat. A slight tap with a hard substance suffices to initiate this transformation. Touching one of the angles with a hot body equally produces the effect. And it is also produced by an electric spark. A temperature below that of boiling water sufficed to cause the change; and Mr. Gore found that in proportion as the whole mass was raised towards this temperature, the metamorphosis, more easily set up, travelled with greater rapidity. When a copper wire was coated with a film of this amorphous antimony, the allotropic change progressed along it at a rate varying from 12 to 30 feet in a minute. Absorption of the evolved heat by the copper wire, was found to be the cause of retardation when the change advanced slowly; whence it follows that were none of the disengaged heat allowed to escape, the wave of change would travel much faster. A further significant fact is that when this transformation was propagated through some amorphous antimony that had been previously reduced to powder, part of it was oxidized—the disturbance caused by the allotropic change initiated chemical change, in parts of the substance that were favourably circumstanced for chemical change. See then the parallelism. We have the transformation set up indifferently, as in nerve, by mechanical force, heat, electricity. We have it facilitated, as in nerve, by raised temperature. We have it travelling from end to end of a mass with a velocity which, though far less than that of the nerve-wave, is still considerable. And we have allotropic change initiating chemical change, just as we concluded that isomeric change in a nerve-fibre sets up chemical change in a nerve-vesicle. Let me not omit an interpretation of nerve-structure, which is suggested by Mr. Gore's experience that the transmission of the allotropic change is rapid in proportion as the evolved heat is retained. In developed animals, nerve-fibres are surrounded by sheaths of medullary matter; and we saw reasons for concluding that this medullary matter is an insulator. Now it has recently been discovered that white or fibrous nerve-tissue, is chemically distinguished from grey or vesicular nerve-tissue, by the

§ 35. Allied with the fact that a nerve-disturbance takes an appreciable time to travel from periphery to centre or from centre to periphery, is the fact that the effect produced

presence in large quantity of a substance called *protagon;* and this substance proves to be of excessively complex composition—has a molecule more highly compounded than any other known molecule. But in proportion as molecules become complex and large, the masses formed of them become bad conductors of molecular motion. It is inferable, then, that the essential nerve-fibre is imbedded in a substance especially distinguished by inability to absorb the molecular motion disengaged during the isomeric change of the nerve-fibre.

I have hitherto passed over without remark, the hypothesis at one time current, and still surviving in some minds, that the nervous force is either electricity or some form of force allied to it. In addition to the many foregoing reasons for adopting another hypothesis, it may be well to set down here the reasons for rejecting this. The highest rate of the nervous discharge is some 32 yards per second. The electric discharge travels at the rate of 280,000 miles per second. The one velocity is thus nearly 16,000,000 times the other. That a force allied to the electric should have a velocity so enormously different, seems very unlikely. Again, an electric current, so long as its source is unexhausted and the circuit unbroken, is a continuous current; but the nerve-current is not continuous. Hence if the nerve-force is of a kind allied to the electric, its mode of alliance is quite exceptional; for the other allied forces, heat, light, and magnetism, are not intermittent. Once more, nervous transmission is facilitated by heat; whereas heat is an obstacle to electric transmission, and diminishes or destroys magnetic action. The fact is that but for the accidental observation of Galvani, the suspicion that the nerve-force is electric or quasi-electric, would probably never have been entertained; and it should have been abandoned as soon as it was found that other disturbing agents, physical and chemical, work just the same effects. The conception has, indeed, been kept alive by the discovery that electricity is generated by certain fishes. But the supposed support is wholly imaginary. If because the Torpedo evolves electricity by the help of nerves ramifying through its electric organ, it is inferred that the nerve-force is electricity; it may in like manner be inferred that the nerve-force is sensible motion, because it generates sensible motion in muscles. But, it may be asked, do not the experiments of Du Bois-Reymond yield support to the hypothesis? A very doubtful support I think. The phenomena he describes may well be merely incidental accompaniments of actions that are in themselves neither electric nor quasi-electric. The truth that both molar and molecular changes in the distribution of matter habitually destroy the electric equilibrium, would be a sufficient general justification for this belief. But there is a special justification. Direct proof exists that the

at the centre or at the periphery lasts an appreciable time. That muscular contraction is continuous though the stimulus is intermittent, goes to show this. The genesis of molecular modification in muscle by the molecular modification in the nerve-fibres permeating it, has a duration that bridges the interval between each pulse of stimulus and the next. We have no direct proof that a like continuity of state results from the successive waves propagated to a nerve-centre; for the actions of which nerve-centres are the seats are not objectively perceptible. But we shall presently find abundant indirect proof that these changes also last for measurable periods.

This general truth, like its predecessor, may be regarded as a corollary from what has gone before. The transformations classed as chemical take time, equally with those classed as isomeric. It is true that explosions due to chemical action are what we call instantaneous (a description of them which is not, however, scientifically accurate; as may be perceived when the matter exploded is of con-

particular kind of molecular change we have supposed to take place in nerve, and in muscle, is adequate to produce the phenomena observed by Du Bois-Reymond. Mr. Gore found that if a copper-wire, coated with amorphous antimony, formed part of an electric circuit, it happened that whenever the allotropic change propagated along the antimony stopped, the galvanometer-needle was deflected. Now, since during the maintenance of a muscular contraction, nerve-pulses are continually arriving and ceasing, and the muscular fibres (never all in action together) are at every instant some of them contracting and some relaxing, it follows that there will be a succession of stoppages of isomeric changes. Consequently there will be a maintenance of deflection in the galvanometer if a contracted muscle forms part of the electric circuit.

[Since this note has been in type, I have referred to the lecture delivered by M. Du Bois-Reymond at the Royal Institution on April 13, 1866, "*On the Time required for the Transmission of Volition and Sensation through the Nerves,*" for the purpose of verifying one of the statements above made; and I find that at the close of this lecture he goes a long way towards abandoning his hypothesis. Though he says "it would be rash, as the matter stands, entirely to dismiss the notion of electricity being concerned;" and though he sketches out a theory of nerve-composition such as makes it conceivable that an electric disturbance might travel along a nerve

siderable bulk). But explosions occur only in those exceptional cases where the elements concerned are either, as in detonating compounds, distributed among one another molecularly, or, as in gunpowder, with minute intimacy. In ordinary cases, where sensible masses of the elements concerned are external to one another, the chemical actions, limited to the surfaces of contact, proceed with comparative slowness. Now the granular protoplasm contained in and around nerve-vesicles, forms, with its permeating liquids and the blood in adjacent capillaries, a mass of which the components are but imperfectly interfused; and therefore a chemical change cannot pass through it instantly. Hence between the reception of a pulse of molecular motion by a nerve-centre, and the emission of a gush of molecular motion, or discharge, some little time must elapse.

§ 36. If a nerve-centre that receives a stimulus through an incoming nerve, undergoes a chemical change and sends

at the observed rate (basing this, however, on the gratuitous assumption that the molecules of nerve-matter have north and south poles); yet he admits that much evidence points another way. He says that "to identify it (the nervous agent) with the electric current as it circulates in a telegraph-wire must appear hopeless, even if a circuit, such as would be necessary for the supposed nerve current to circulate in, were anatomically demonstrated. Thus to the other arguments against this view of the nervous agent—that the resistance of the nerve-tubes would be far too great for any battery to send an available current through them—that the physiological insulation of the nerve-tubes from each other would be impossible to explain—that the effect of ligature or of cutting the nerve and causing its ends to meet again, would be equally obscure—to these arguments, unanswerable as they are in themselves, the researches sketched in this lecture have added corroborative evidence of the highest order. What we have termed the nervous agent, if we look upon its very small velocity, in all probability is some internal motion, perhaps even some chemical change, of the substance itself contained in the nerve-tubes, spreading along the tubes, according to the speaker's experiments, both ways from any point where the equilibrium has been disturbed; being capable of an almost infinite number of variations or gradations, and of so peculiar a character as to require the unimpaired condition of the nervous structure."]

a discharge along out-going nerves, it thereupon becomes less capable of emitting such discharges in response to such stimuli. The quantity of molecular motion locked up in a nerve-centre, is measured by the contained quantity of unstable nerve-matter; and decomposition of that part of the unstable nerve-matter which was most favourably placed for being acted on, leaves not only a diminished quantity but a quantity that is less favourably placed for being acted on—leaves, therefore, a decreased readiness to undergo change when disturbed, as well as a decreased stock of molecular motion to be liberated. Consequently, other things remaining the same, every excitation of a nerve-centre reduces, for a time, its impressibility and its energy.

This temporary enfeeblement of a nerve-centre, when caused by moderate action, is inconspicuous. The disintegrated mass quickly re-integrates itself from the materials brought by the blood. But if the stimulation and consequent discharge are violent, or if stimulations and discharges are repeated very rapidly, then repair falls so far in arrear of waste that partial or entire incapacity of the nerve-centre results. All its unstable substance within easy reach of in-coming disturbances has been decomposed; leaving such part only of its unstable substance as is most removed from disturbances, and can be affected only by excessive ones. A well-known experiment on the vaso-motor system of a frog, may be cited in illustration. If a frog's foot be placed under a microscope, and so adjusted that the arteries ramifying through the transparent membrane between the toes are brought into view, then, if a powerful irritant be applied to this membrane, the first result observed is that these arteries are violently constricted —the strong impression conveyed to the vaso-motor centres there liberates an excessive discharge along the fibres supplying these arteries, causing spasmodic contractions of their muscular coats. The second result is that these

arteries dilate: losing their normal contractility they become distended with blood, and the part is, as we say, congested. That this is due to extreme prostration or temporary paralysis of the vaso-motor centre, has been clearly proved; for if the nerve-trunk containing the vaso-motor fibres be dissected out and artificially irritated, the dilated arteries instantly contract. How a nerve-centre may be prostrated by a rapid succession of moderate stimuli and discharges, instead of by one violent stimulus and discharge, is shown by the familiar effect of friction on the human skin. A single moderate rub causes only a slight reflex action on its vessels, and leaves the vaso-motor apparatus ready to act afresh with no apparent diminution of power. But a series of rubs is followed by temporary congestion of the vessels: it is some little time before the vaso-motor centre regains its full control over them. And if the skin be continuously chafed, the excessive waste and debility of the vaso-motor centre entail that enduring redness called congestion. Those parts of the nervous system concerned in muscular action, daily illustrate the same general relation. Fatigue is a state in which the ability to generate motion has been greatly diminished by long-continued genesis of motion; and every tired horse shows, by the small response he makes to a cut of the whip, that a more violent impulse must be propagated to the nerve-centres to cause the ordinary evolution of nervous energy.

Irregularities in the manifestation of this truth, are due to that entanglement of the conditions which was indicated at the close of the last chapter. It frequently happens, for instance, that after performing its function for some time, a nerve-centre responds to the demands on it better than at first—a fact apparently at variance with the foregoing conclusion. But this conclusion supposes all the circumstances to have remained the same; and in such cases they have not remained the same. There has been an exaltation of the heart's action, or a local increase in the quantity of blood, or

a more rapid aëration of blood, or all of these. When every appliance which furthers the disintegration and re-integration of a nerve-centre, has been brought into full play, both waste and repair go on faster; and there result greater impressibility and energy than when the previously-unused centre contained but little blood languidly circulating.

§ 37. Were Life uniform in its rate—were terrestrial conditions such that actions of all kinds could be performed as readily at one time as at another, repair and waste of all organs, including nervous organs, would have to keep an approximately-even pace, one with the other. But the alternation of day and night entails an alternation of greater and less facility for actions; and there has resulted in organisms an adapted alternation in the relative rates of waste and repair. The adaptation is manifestly due to survival of the fittest. An animal so constituted that waste and repair were balanced from moment to moment throughout the twenty-four hours, would, other things equal, be overcome by an enemy or competitor that could evolve greater energy during the hours when light facilitates action, at the expense of being less energetic during the hours of darkness and concealment. Hence there has necessarily established itself that rhythmical variation in nervous activity, which we see in sleep and waking. Let us observe how these are interpretable, the one as a state of the nervous centres in which waste has got considerably in excess of repair, and the other as a state in which repair has made up for previous excess of waste.

Confining ourselves to persons whose functional rhythms have not been deranged by undue excitements, we see that after some sitxeen or eighteen hours of sustained impressibility and energy, there is a diminished readiness to respond to stimuli that fall on the eyes, ears, and surface of the body at large; and presently this becomes so pronounced that loud sounds and the irritations produced by strained attitudes, fail to evoke movements. When great exertion has

been gone through, or when previous intervals of sleep have been omitted, the decrease of impressibility is such that tickling the nostrils or pinching the skin does nothing more than cause, perhaps, a reflex start. This change, so marked and often so rapidly established, seems greater than the alleged cause can produce; but it is fully accounted for when we include an indirect effect of this cause. The waste of the nerve-centres having become such that the stimuli received from the external world no longer suffice to call forth from them adequate discharges, there results a diminished impulse to those internal organs which subserve nervous activity, including, more especially, the heart. Consequently the nerve-centres, already working feebly, are supplied with less blood and begin to work more feebly—respond still less to impressions, and discharge still less to the heart. And so the two act and re-act until there is reached this state of profound unimpressibility and inactivity.

Between this state and the waking state, the essential distinction is a great reduction of waste. Certainly in some nervous centres and probably in all, waste does not absolutely cease: there continue those emissions of force which keep up the vital processes; and it is, I think, unlikely that there is ever an entire stoppage of those changes which take place in the highest centres. But the rate of waste falls so low that the rate of repair exceeds it. It is not that during the period of activity waste goes on without repair, while during the period of inactivity repair goes on without waste; for the two always go on together. Very possibly—probably even—repair is as rapid during the day as during the night: perhaps even more rapid: for the blood is on the average richer and circulates faster. But during the day the loss is greater than the gain, whereas during the night the gain is diminished by scarcely any loss. Hence results accumulation: there is a restoration of the nerve-tissue to its state of integrity.

In the course of some hours this restoration begins to

show its effects in returning impressibility. While in sleepiness we see a decreasing readiness to respond to external stimuli, the approach to a waking state is characterized by an increasing readiness to respond to external stimuli. Throughout the period of quiescence the afferent nerves remain subject to incident forces. The pressure of the body on the bed affects some of them, and others are affected by the touch of the bed-clothes; degrees of heat a little above or below the average, act on others; and yet others receive sonorous vibrations constantly occurring. But whereas sleep results because the centres worn by action become less and less sensitive to these stimuli, waking results because the centres repaired during rest become more and more sensitive to them. The strains of muscles and ligaments which during the first part of the night fail to cause changes of attitude, cause such changes towards morning. The amount of light that traverses the eye-lids presently suffices to call forth movements. Some slight noise which, hours before, would have had no effect, now produces a start. Even in the absence of external stimuli (which, however, can never be absent) there are the stimuli from the viscera, and especially from the alimentary canal: an empty stomach eventually sends to the cerebro-spinal system enough disturbance to end the quiescent state. The longer repair goes on unopposed by appreciable waste, the greater must become the instability of the nerve-centres, and the greater their readiness to act; so that there must at length come a time when the slightest impressions will produce motions. Such impressions, however slight, are necessary antecedents. The re-integrated nerve-centres do not resume their activity until an impulse arriving from the periphery overthrows some of their molecules. Evidence of this is furnished to most every morning. On awakening from refreshing sleep, there commonly occurs an involuntary stretching of the muscles of the whole body; showing an immense undirected motor discharge. But this is not the

initial fact. No one awakes to find himself then and there stretching; which might happen were the discharge spontaneous. It comes after those stronger disturbances that are propagated to the centres, as soon as some slight disturbance has led to the slight movements that accompany waking. A trifling sound causes opening of the eyes and a turn of the head. Thereupon follow vivid impressions through the eyes, through the skin that rubs against the bed-clothes, and through the muscles that set up the movements. And a relatively-large aggregate of stimuli being sent from the periphery, there results this relatively large gush of motor excitement.

On pursuing the argument we may understand why the energies continue to rise for some time after awaking. We saw that when once sleepiness has commenced, it increases because in proportion as the nervous centres fail in their discharges, the heart, losing part of its stimulus, begins to flag, and that the flagging of the heart leads to a greater inertness of the nerve-centres, which re-acts as before. Conversely, it will here be manifest that when the nerve-centres, repaired by sleep, become again ready for discharging with vigour, there take place an action and re-action which have the opposite effect. The pulsations on awaking are comparatively feeble. As soon as stimuli begin to be received through the sensory organs, and the discharges of the nerve-centres are renewed, the heart comes in for its share of these and acts more vigorously. By so doing it supplies the nerve-centres with more blood in quicker gushes. A greater nervous discharge is thereby made possible, which again, among other results, exalts the heart's action. And so the mutual aid goes on: the greatest nervous vigour being reached when the vascular activity has been still further raised by a meal, and the blood has been enriched by the absorbed materials.

§ 38. As implied by much that has gone before, and as

especially implied by the last section, nervous stimulation and nervous discharge have always both special and general results. Beyond the primary and definite effect wrought on a particular part by a particular impression, there are in every case secondary and indefinite effects diffused through the whole nervous system, and by it through the body at large.

It was pointed out (§§ 10, 11) that the simplest nerve-centre puts in relation not afferent and efferent fibres alone; but that through other fibres, commissural and centripetal, connections are made between it and other nerve-centres of the same grade and of a higher grade. Further, we saw that when such a nerve-centre is excited through an afferent nerve, the disengaged molecular motion does not escape wholly along one or more efferent nerves; but that part of it, propagated to higher centres, there sets up supplementary changes. The diffusion does not stop here—remoter parts are reached; and thus the disturbance of a single nerve-fibre, if at all considerable, reverberates throughout the entire nervous system, and affects all the functions controlled by it. Digging a pin into the foot may cause a convulsive contraction not of the leg-muscles only, but of many other muscles throughout the body. At the same time it may alter the rate of pulsation, and send waves of constriction along the arteries. The excreting structures of the skin may be so affected that a burst of perspiration results; and the actions going on throughout the alimentary canal may be deranged. Such reverberations, which become conspicuous when the disturbances are decided, take place also when they are slight. A more vivid light, causing as it does stronger pulses of change through the optic nerve, increases the rate of respiration; and doubtless the other vital functions are simultaneously exalted. So that each nervous impression, beyond a direct response in the shape of increased action from one or more organs, calls forth an indirect response in the shape of increased action of the organism as a whole.

Remembering that every instant the disturbance thus echoing throughout all passages of the nervous system is not solitary, but that there are many such disturbances, here arising from pressure there from touch, in this place produced by sound and in that by light, at one part by muscular strain and at another by heat or cold; it will be manifest that, besides the few distinct waves of nervous change working their distinct effects, there are multitudinous indistinct waves, secondary and tertiary, travelling in all directions working their indistinct effects.

§ 39. Since such reflected and re-reflected disturbances everywhere act as stimuli, we must regard the entire nervous system as at all times discharging itself. The unstable molecules of its centres, exposed to this confused reverberation, are liable to be decomposed wherever a concurrence of small waves makes the local agitation considerable; and the molecular motion thereupon disengaged, adds to the centrifugal gush perpetually going on. Rightly to conceive nervous action then, we must think of the conspicuous emissions of force from parts of the nervous system that are strongly disturbed, as standing out from a vague back-ground of inconspicuous emissions from the whole nervous system, which is slightly disturbed.

To this general nervous disturbance with its consequent general discharge, is probably due a certain general action of the motor organs. No muscles are ever in a state of absolute rest. What we distinguish as muscular motion is produced by the greater contraction of some muscles than of others. The others, however, are all slightly contracted; and would severally produce motion were they not balanced or out-balanced by their antagonist muscles. This pervading activity of the muscles is called their tonic state. And while we regard particular contractions as the results of particular nervous discharges, we have good reasons for concluding that this universal contraction is the result

of the universal nervous discharge. Here are a few of them. Sleep, as above explained, implies diminished nervous discharge, special and general. A diminution of the general discharge ought, then, to be shown in a decrease of the tonic contraction. It is so shown. Falling asleep is accompanied by muscular relaxation: though previously the attitude was such that no effort seemed requisite to maintain it; yet that there was some muscular strain, and that it has suddenly become less, is proved by the sliding down of a limb, or of the head, to a more stable position. Certain disorders, as palsy, yield further proof. The flexors and extensors which, when duly contracted, serve by their balanced antagonism to hold a limb steady, cease to do this when the general nervous discharge is not great enough to keep them and all other muscles braced up: in default of sufficient stimulus for both, now one set and now the other fails to put the due check on its opponent. That such shakings are so caused, we see clearly in persons debilitated by over-stimulation; for in them this symptom may be temporarily mitigated, or almost cured, by temporarily increasing the general nervous discharge. The drunkard who early in the day cannot lift his glass without spilling the contents, is able to do this after his brain has been excited by the usual doses of alcohol.

Of course it is not the muscles alone on which this continuous centrifugal gush is expended. Through the intermediation of nerves connecting the cerebro-spinal system with the sympathetic system, the viscera receive their share of it. Hence the overflow of nervous energy which, without special solicitations, diffuses itself throughout the motor structures, giving elasticity to the step, and producing the concave bend of the back, the opened-out shoulders, the raised head, &c., has, for its simultaneous results, an accelerated circulation, an invigorated digestion, and an exaltation of the vital processes at large.

§ 40. Briefly reviewed from a somewhat different standpoint, the following are the leading facts which it concerns us to remember.

Nervous stimulations and discharges consist of waves of molecular change, that chase one another rapidly through nerve-fibres. The stimulus or discharge formed of such waves, arises at some place where unstable nerve-substance has been disturbed; and is the same no matter what agent caused the disturbance. The successive waves severally travel with a velocity which, though considerable compared with ordinary sensible motions, is extremely slow compared with other kinds of transmitted molecular motions. And each set of waves, while itself caused by the decomposition of unstable nerve-matter, is a means of decomposing other unstable nerve-matter: so generating further and often stronger sets of waves, which similarly chase one another into many and distant parts of the nervous system.

There is a triple rhythm in these nervous stimulations and discharges—each form of rhythm being due to the greater or less incapacity for action which an action produces. We have seen that every wave of isomeric transformation passing along a nerve-fibre, entails on it a momentary unfitness to convey another wave; and that it recovers its fitness only when its lost molecular motion has been replaced and its unstable state thus restored. We have also seen that any portion of grey matter in a nerve-centre, which having been disturbed and partially decomposed has emitted a shock of molecular change, is proportionately incapacitated; and that it recovers its original ability only as fast as it re-integrates itself from the materials brought by the blood. And then there comes the further rhythm constituted by the alternations of sleep and waking—a rhythm having the same origin as the last, and being supplementary to it.

The remaining truth which we have contemplated is that each special stimulation and the special discharge produced by it, do not together form the whole of every nervous act;

but that there is always an accompanying general stimulation and general discharge. Every part of the nervous system is every instant traversed by waves of molecular change—here strong and here feeble. There is a universal reverberation of secondary waves induced by the stronger primary waves, now arising in this place and now in that; and each nervous act thus helps to excite the general vital processes while it achieves some particular vital process. The recognition of this fact discloses a much closer kinship between the functions of the nervous system and the organic functions at large, than appears on the surface. Though unlike the pulses of the blood in many respects, these pulses of molecular motion are like them in being perpetually generated and diffused throughout the body; and they are also like them in this, that the centripetal waves are comparatively feeble while the centrifugal waves are comparatively strong. To which analogies must be added the no less striking one, that the performance of its office by every part of the body, down even to the smallest, just as much depends on the local gushes of nervous energy as it depends on the local gushes of blood.

CHAPTER VI.

ÆSTHO-PHYSIOLOGY.*

§ 41. Throughout the foregoing chapters nervous phenomena have been formulated in terms of Matter and Motion. If from time to time the phrases used have tacitly referred to another aspect of nervous phenomena, the tacit references have formed no parts of the propositions set down; but have

* This new word will possibly be condemned as not legitimately compounded. The objection that the root from which its prefix is derived, is shorn of its fair proportions, admits, I am told, of a satisfactory answer: from the proximate root, appeal may be made to the original root, which, following the Greek method of forming derivatives, would admit of the required modification. But to the criticism that the word involves the logical inconsistency of uniting a verb with a noun, there is no such sufficient answer. Nevertheless, I deliberately adopt *Æstho-physiology* in preference to the more cumbrous and cacophonous *Æsthesi-physiology*. A progressive integration by which the originally-distinct and numerous parts of compound words become fused together, blurred, and some of them lost, is one of the essential processes in the development of language. If mankind had refrained from the obliteration and disfigurement of roots, and parts of roots, language would have continued wholly inadequate for all but its simplest functions. Omitting those formed by onomatopœia, the best words are those from which long use has worn away all, or nearly all, traces of their origin. We may as well, therefore, begin with abbreviated and modified words when we have to coin them; instead of leaving time to bring about the needful shortening and shaping. Those who, dealing with words as counters, see that their convenience as counters is the chief consideration, will probably coincide in this view; though I suppose it will be wholly disapproved by those who regard words not as counters but as money.

been due to lack of fit words—words free from unfit associations. As already said, the nervous system can be known only as a structure that undergoes and initiates either visible changes, or changes that are representable in terms furnished by the visible world. And thus far we have limited ourselves to generalizing the phenomena which it thus presents to us objectively.

Now, however, we turn to a totally-distinct aspect of our subject. There lies before us a class of facts absolutely without any perceptible or conceivable community of nature with the facts that have occupied us. The truths here to be set down are truths of which the very elements are unknown to physical science. Objective observation and analysis fail us; and subjective observation and analysis must supplement them.

In other words, we have to treat of nervous phenomena as phenomena of consciousness. The changes which, regarded as modes of the *Non-Ego*, have been expressed in terms of motion, have now, regarded as modes of the *Ego*, to be expressed in terms of feeling. Having contemplated these changes on their outsides, we have to contemplate them from their insides. To speak with exactness, indeed, it cannot be said that *we* have so to contemplate these changes; for this expression implies that these changes can be simultaneous witnessed by more than one, which is not true. Rigorously limiting the proposition to that which is alone possible, it amounts to this:—I have to describe the laws of relation between the states of feeling occurring in my own consciousness, and the physical affections of that nervous system which I conclude I possess; and the reader has to observe whether in himself there exist parallel relations between such known states of consciousness and such supposed nervous affections.

This will perhaps be thought a needlessly roundabout, if not a sceptical, statement; but it is in fact not roundabout enough. It does not bring sufficiently into view the re-

motely-inferential character of the belief that feeling and nervous action are correlated. Before proceeding on this belief, let us observe how indirect is the path which leads to it.—1. Each individual is absolutely incapable of knowing any feelings but his own. That there exist other sensations and emotions, is a conclusion implying, in the first place, the reasonings through which he identifies certain objects as bodies of like nature with his own body; and implying, in the second place, the further reasonings which convince him that along with the external actions of these bodies, there go internal states of consciousness like those accompanying such external actions of his own body. 2. This conclusion that there exist beings like himself, and that under like conditions they experience like feelings, even supposing it entirely true (and it is not entirely true, for many facts unite to prove that under like conditions both the quantities and the qualities of sensations and emotions in different individuals differ considerably), by no means implies that what he knows under its subjective aspect as feeling, is, under its objective aspect, nervous action. The average observer has no direct evidence that these other like beings have nervous systems, any more than that he has himself a nervous system; and he has no direct evidence in the one case any more than in the other, that nervous excitations are the causes of feelings. Experimental physiologists and pathologists only have proofs; and even their proofs are mostly indirect. The experiments which yield them are usually made on beings of another and much inferior order. The contractions of muscles and arteries, caused by irritating nerve-trunks in frogs, the convulsive movements, and sometimes the sounds, made by birds and mammals whose nerve-centres are variously injured—these are the phenomena from which it is inferred that the human nervous system is the seat of the human feelings, and that these feelings are the correlatives of its excitations: the only important verifications of the inference being those

obtained during surgical operations where nerve-trunks are cut through, and those furnished by *post mortem* examinations of morbid nervous structures in the bodies of those who when alive displayed abnormal excesses or defects of feeling. 3. And then, having learnt at second hand, through the remotely-inferential interpretation of verbal signs, that in now one and now another of the bodies he recognizes as like his own there has been found a nervous system, and that the stimulations of this produce those manifestations which in himself accompany feelings, the reader imagines a nervous system contained in his own body, and concludes that his sensations and emotions are due to the disturbances which the outer world sets up at its periphery, and arouses by indirect processes in its centres. Such, stated as briefly as possible, is the long and involved series of steps by which alone the connection between nervous action and feeling can be established.

Nevertheless, the evidence of this connection is so large in amount, presents such a congruity under so great a variety of circumstances, and is so continually confirmed by the correct anticipations to which it leads, that we can entertain nothing more than a theoretical doubt of its truth. Here accepting the belief, alike popular and scientific, that all the human beings known objectively have feelings like those which each knows subjectively; and accepting also the belief, originating with science but now diffused through the general mind, that feelings are the concomitants of nervous changes; we will proceed to consider the relation between feelings and nervous changes under its leading aspects.

§ 42. And first let us observe that the circumstances conducive to the one are identical with the circumstances conducive to the other. The conditions which we before found essential to the production of nervous action, we shall now find essential to the production of feeling. We may pass

over the evidences briefly, as being many of them the inner aspects of phenomena already observed under their outer aspects.

That without continuity of nerve-fibre between periphery and centre, a disturbance at the one causes no feeling at the other, is proved to every one who has cut himself deeply: for a long time the part that has had its nervous communication destroyed, remains numb. This experience, usually very limited in each person, is borne out by the testimony of those seriously injured; and especially by the testimony of those whose sensations over large parts of their bodies have ceased, and who, after death, are found to have lesions in the conducting structures of the nervous centres.

The hindrance or prevention of feeling by pressure, is illustrated by the numbness of a limb so placed that its whole weight, and perhaps the weight of another limb lying over it, comes on the edge say of a table; so that great stress is borne by some portion of the chief nerve-trunk. Local anæsthesia thus caused in strong persons, is caused still more readily in feeble persons; who, on awaking, not unfrequently find complete insensibility of the parts that have been pressed against the bed during sleep.

Ability to feel depends on the maintenance of a certain temperature. This also is a general truth of which some proof is furnished to every individual by his own experience—or, at any rate, to every individual inhabiting a climate where the winter's frost suffices greatly to chill the extremities. Evidence much stronger but indirect, is given him by those who have undergone surgical operations in parts deprived of feeling by freezing mixtures or by ether-spray. Loss of local sensibility from local cold, ordinarily not very manifest unless the cold is great, becomes manifest when the cold is slight if the circumstances supply a delicate test. This is interestingly shown among compositors. The air of a printing-office has to be kept very warm, even at

the expense of unhealthy closeness; otherwise the fingers of the compositors cease to lay hold of, and manipulate, the types with the requisite nicety and speed.

Few persons have immediate experience of the fact that defect of blood in a part causes defective sensibility of that part; but all persons have immediate experience of the local exaltation of sensibility that accompanies local excess of blood. The inflamed neighbourhood of a wound, or even the surface of a pimple, yields to consciousness when touched, an amount of feeling far greater than is yielded by a part of the skin supplied with the ordinary amount of blood. Special organs of touch show us well the increased sensitiveness thus caused. When one of those sacs containing the bulbs of the small hairs scattered over the skin, is congested, the rubbing of the clothes against the hair growing from it, especially if it has been broken short, produces an unbearable smart. Among evidences yielded by the other senses, a familiar one is the intolerance of light that goes along with inflammation of the eyes. And there is an unfamiliar one particularly worth noting, because it exhibits the effect due to increased quantity of blood apart from increased temperature. The observation may be made when taking a hot bath. Let the water be above blood-heat—say 100° Fh. After remaining quiet for a time until equally heated all over, stand up and rub one portion of the body with a flesh-brush until it is red. Pause a few moments, and lie down again in the water. It will then be perceived that to the reddened part the water seems much hotter than it does to any other part.*

That degree of feeling is affected by quality of blood as well as by quantity, is a truth not easily discerned within the

* This fact yields proof, if there needs any, that the nerves which appreciate temperature are not the nerves of touch. Violent friction must produce a momentary incapacity of the nerves of touch; and this incapacity would be shown in a decreased, instead of an increased, appreciation of temperature, were they the agents concerned.

experiences of each individual, if attention is limited to those variations of feeling that accompany naturally-produced variations in quality of blood. For such variations cannot be identified with precision; and they arise so slowly that the concomitant mental states cannot be brought into close contiguity, so as to bring out their contrasts clearly. But by making certain artificial additions to the blood, every one gets proof of the connection between its quality and the genesis of feeling. The effects of stimulants on consciousness are mostly traced in the intensification of those internally-initiated feelings with which we shall deal presently; but they may also sometimes be traced in the intensification of the externally-initiated feelings. In nervous subjects, ordinary impressions on the senses are often rendered abnormally acute by tonics. When under the influence of opium, music that was previously unenjoyed may be greatly enjoyed; and it is a well-known result of hashish to give an excessive vividness to the sensations.

How, contrariwise, there are substances which, when added to the blood, render sentiency less vivid, is shown by other facts similarly reached. We have sedative medicines—medicines that diminish the amounts of painful consciousness caused by irritations at the periphery of the nervous system. And we have agents of the same class called anæsthetics, which, in a still greater degree, hinder the genesis of feelings by the actions that usually generate them. These effects so caused, help us to understand the stupor produced by the natural anæsthetics, carbonic acid and urea; and prove that some variations in degree of feeling are determined by variations in the activities of excreting organs.

§ 43. Now that we have noted how feelings and nervous changes are facilitated or hindered by the same conditions, we may go on to collate them in detail. Let us begin by distin-

guishing those nervous changes which are accompanied by feelings from those which are not. For, as we noted in passing, several classes of them have objective aspects only—do not present inner faces to consciousness; and others have subjective aspects in early life but cease to have them in adult life.

Chief among the nervous changes that have no identifiable subjective aspects, are those occurring in the visceral nervous system. So long as they are normal in their amounts, the stimulations and discharges of which the sympathetic is the seat, go on without sensations; and even when abnormal, the resulting discomfort or pain is probably not due to them but to disturbance of those cerebro-spinal fibres which accompany the sympathetic through all its branchings. Similarly with the local ganglia and fibres of the heart. Ordinarily there is no consciousness of the heart's action; and even when the pulsations are violent, the modifications of consciousness do not arise from the state of the heart's nervous system, but from disturbance of cerebro-spinal nerves caused by the bounds of the heart against adjacent structures. The like holds with the vaso-motor nerves. Under ordinary conditions these regulate the diameters of the arteries without our knowing anything about it; and though where, as in a blush, great dilatation of the vessels has been produced, we are made aware of their action, yet we are made aware of it indirectly, through the local change in the quantity of blood and the consequent effect on the nerves that appreciate temperature.

The majority of stimulations and discharges occurring in the spinal cord, have subjective accompaniments. These, however, are not localized at those points in the spinal cord where the essential nervous changes take place; as is proved by the fact that when some lesion of the spinal cord which has not injured its lower part, has cut off communication with the brain, the reflex acts performed by this lower part are unconscious. Proceeding upon the inference

before drawn (§21) that when a wave of disturbance brought by an afferent nerve to a spinal centre, liberates a quantity of molecular motion, a portion of it, not discharged along the efferent nerves, is propagated through a centripetal nerve to a higher centre, we may conclude that it is this portion which comes, in the higher centre, to have a subjective aspect as a sensation: being there joined with other sensations and feelings of other orders into a chain of states of consciousness, out of which no sensation is ever known to exist. For recognition of a sensation as such or such, necessitates the bringing of it into relation with the continuous series of sentient states, from some of which, simultaneously experienced, it is dissociated by perceived unlikeness, and with others of which, previously experienced, it is associated by perceived likeness; and the implied comparisons of sentient states are impossible unless the correlative nervous changes are put in connexion at one place. It does not follow, as it at first seems to do, that feelings are never located in the inferior nervous centres. On the contrary, it may well be that in lower types the homologues of these inferior centres are the seats of consciousness. The true implication is that in any case the seat of consciousness is that nervous centre to which, mediately or immediately, the most heterogeneous impressions are brought; and it is not improbable that in the course of nervous evolution, centres that were once the highest are supplanted by others in which co-ordination is carried a stage further, and which thereupon become the places of feeling, while the centres before predominant become automatic.

Quite congruous with this conception is the above-named fact, that certain nervous changes which have subjective sides early in life cease to have them later in life. Many acts performed by the child slowly and consciously, the adult performs rapidly and unconsciously. Every step taken during the first efforts to walk has its accompanying

distinct feelings; but eventually, the successive steps are made while consciousness is wholly or almost wholly occupied with other feelings. Still better is the illustration furnished by speech. Each muscular adjustment of the vocal organs and each articulate sound made, have, in childhood, concomitant sentient states that are vivid, and, for the moment, all-absorbing. Gradually, however, these become less dominant in consciousness; until at maturity there is entire oblivion of the one, and sometimes partial oblivion of the other: witness the not unfrequent verbal mistakes unconsciously made in the heat of discussion. Now facts of this kind, countless in number and of many varieties, are explicable if we regard feelings as the subjective sides of such nervous changes only, as are brought to the general centre of nervous connections. When we remember that early in life each inferior ganglion, or cluster of co-operating inferior ganglia, is imperfectly organized, and the connections among its fibres incomplete; we shall see that if there comes to it a disturbance, the gush of molecular motion liberated, not having in the incompletely-connected commissural and efferent fibres, adequate channels of escape, will part of it escape along a centripetal fibre to a higher centre, so awakening a feeling. And it will manifestly happen that the approach to automatic action of the lower centre, will be an approach to a state in which the liberated molecular motion, having in the efferent fibres fully-opened channels of emission, will little or none of it be forced into centripetal fibres, and will so awaken little or no feeling. It is a corollary from this interpretation, that all gradations will exist between wholly unconscious nervous actions and wholly conscious ones; since there will be all gradations in the relative amounts of the disturbances which take their courses along centripetal fibres. It obviously follows, too, that in adult life a nervous action may or may not have an identifiable subjective aspect, according as it is strong or weak; since, if there comes

to a finished ganglion constructed as described, a feeble disturbance, the whole of the small quantity of molecular motion liberated may be drafted off by the efferent fibres; whereas, if the disturbance is great, the disengaged molecular motion, being more than can find its way along the efferent fibres, will some of it take a centripetal course and cause a subjective change.

§ 44. A kindred aspect of this correlation presents itself when we contemplate feeling as occupying time. A subjective state becomes recognizable as such, only when it has an appreciable duration: it must fill some space in the series of states, otherwise it is not known as present. This general truth harmonizes with a general truth before pointed out respecting nervous action, as well as with the above interpretation.

The observed fact that time is taken in the transit of a nerve-wave, is not to the point; for this transit has no concomitant subjective state. But the inferred fact that the change set up in a nerve-centre must take time, and a more considerable time (§ 35), is relevant; for what is objectively a change in a superior nerve-centre is subjectively a feeling, and the duration of it under the one aspect measures the duration of it under the other.

That feeling persists after the force arousing it ceases, is not proved by the lengthened sensation produced by a moderate blow on the skin, or by that which follows dipping the hand into hot-water, or by those which the palate and the nostrils experience from pungent substances momentarily applied; for though in such cases the external action of the exciting agency is brief, the local changes it sets up, lasting some time, continue for some time to disturb the local nerve-fibres. But good evidence is supplied by impressions on the retina. To quote the words of Professor Huxley:—"A flash of lightning is, practically, instantaneous, but the sensation of light produced by that

flash endures for an appreciable period. It is found, in fact, that a luminous impression lasts for about one-eighth of a second; whence it follows, that if any two luminous impressions are separated by a less interval, they are not distinguished from one another. For this reason a 'Catherine-wheel,' or a lighted stick turned round very rapidly by the hand, appears as a circle of fire; and the spokes of a coach-wheel at speed are not separately visible, but only appear as a sort of opacity, or film, within the tire of the wheel."

As above said, this general truth that feeling implies time, harmonizes with the interpretation given in the preceding section; and supplies a further elucidation of the relation between conscious and unconscious nervous action. For manifestly, in proportion as nervous co-ordinations become more automatic they become more rapid; and for this reason also, cease to present such conspicuous subjective aspects. Returning to the inferior ganglion, or cluster of co-operating ganglia, above described, it will be obvious that a state in which the local organization is incomplete, and the various afferent and commissural fibres not brought into definite relations with vesicles, and through them with efferent fibres, must be a state in which the molecular motion liberated by an incoming shock of change, will pass through the imperfectly differentiated structure with comparative slowness; and there will therefore be an appreciable time during which centripetal fibres may receive disturbance. But as fast as the local connections of fibres and cells become complete, the gush of molecular motion, following the completely-formed channels, will escape rapidly; and the period during which excitement of the centripetal fibres may take place will be abridged. The concomitant subjective state will therefore be rendered shorter by the same change that renders it feebler.

§ 45. The fact that each feeling lasts an appreciable time, introduces us to the allied fact that each feeling produces a greater or less incapacity for a similar feeling, which also lasts an appreciable time. This, too, is the subjective side of a phenomenon before noticed under its objective side (§ 36). For as the duration of a feeling answers to the duration of the molecular disintegration in a disturbed nerve-centre; so the subsequent interval of diminished ability to feel, answers to the interval during which the disintegrated nerve-centre is re-integrating itself. Let us observe how among sensations of all kinds we may trace conformity to this law.

An illustration is supplied by the sense of touch. If the fingers be repeatedly swept rapidly over something covered by numerous small prominences, as the papillated surface of an ordinary counterpane, a peculiar feeling of numbness in them results: the objects touched the moment after seem smoother than usual; implying that the small irregularities on them produce less vivid impressions. That the sensation of muscular tension undergoes a variation similarly caused, everyone knows. After carrying a very heavy body in the hand for some time, a small body held in the same hand appears to have lost its weight; showing that the nerve-centre which is the seat of the sensation has been, for the moment, rendered obtuse. How the gustatory faculty is exhausted for a time by a strong taste, daily experience teaches. When sugar or honey has just been eaten, things that are but slightly sweetened seem to have no sweetness. While the palate is still hot with a curry, an unflavoured dish seems insipid; and a glass of liqueur is fatal to the appreciation of a choice wine. Even more marked is that incapacity of the sense of smell caused in like manner. The intensity of the pleasurable feeling given by a rose held to the nostrils, rapidly diminishes; and when the sniffs have been continued for some time, scarcely any scent can be per-

ceived. A few minutes' rest partially restores the impressibility; but a long interval must elapse before the odour is enjoyed as keenly as at first. This quick exhaustion, producing in such cases some disappointment, has its correlative advantage when the smells are disagreeable. Very soon these become much less perceptible; and to those living in it a stench gives scarcely any annoyance. The feelings generated by sonorous vibrations rarely show us this variation in a marked degree; being, as they commonly are, too short to leave much nervous prostration. A strong taste, or odour, or sensation of muscular tension, is due to an action on the nerves that is maintained for a considerable time; but the actions to which are due those loud sounds required to cause temporary unimpressibility, are mostly very brief. Illustrations are to be expected only in special cases; and in these we find them. The bang of a cannon is described as deafening by those who are close to the cannon when it is fired, because they are rendered for a time partially deaf to ordinary sounds. On men engaged in artillery-practice, the repeated explosions entail a dulness of hearing that lasts for hours; and this dulness of hearing becomes permanent in those who are permanently occupied in such practice. Numerous and very conclusive proofs are supplied by the feelings we receive from light. There are two classes of them: those showing us a variable sensibility to light in general, as contrasted with darkness; and those showing us a variable sensibility to each kind of light—each colour. Under the one head the reader may first be reminded of the experience that on going out of broad sunshine into a dimly-lighted place, it is impossible to discern the surrounding objects: only after a time do they become faintly visible, and a considerable interval elapses before they are seen with clearness. Disabilities similarly caused are disclosed, when, instead of acting on the retinæ as wholes, we act differently on their different parts. Hence what are called

negative images. If, after gazing for some moments at an object presenting strong contrasts of light and dark parts, the eyes are turned towards a shaded space, containing nothing conspicuous, there will be perceived a transient image of the object, in which the light and dark parts are reversed. The interpretation of this fact is that those portions of each retina on which strong light had fallen, together with the answering portions of the optic centres, having undergone the most change with corresponding production of the most feeling, are the next instant less capable of undergoing change and evolving feeling than the portions on which feeble light had fallen; and hence, when they are together exposed to the same feeble light, the unexhausted parts appreciate it more than the exhausted parts, and a negative image results. The cases of the second class are the well-known phenomena of subjective complementary colours. After looking intently at a surface of bright red, an adjacent surface of white seems to have a greenish tint. The explanation is obvious. Those nervous elements changed by the rays which produce in us the sensation of redness, having been partially incapacitated, the red rays contained in the white light cause less of their appropriate effect than usual; while the blue and yellow rays causing their usual effects, and therefore relatively-predominant effects, a sensation of greenness arises.

This decrease in the susceptibility to a feeling of any kind, which immediately follows a feeling of that kind, is not a constant decrease. It is a decrease that varies greatly in degree; and from its variation we may derive further instructive evidence. Other things equal, it is small or great according to the great or small constitutional vigour. One of these disabilities lasts for a scarcely appreciable time when the vital activities are high; and lasts for a time that becomes longer and longer as the vital activities flag. Abundant proof of this is

furnished by the negative images just described. In youth these are scarcely if at all to be observed: only when an extremely-vivid retinal impression has been produced, as by looking at the Sun, is the negative image perceptible. But in middle life and afterwards, especially in debilitated persons, negative images of ordinary objects are very commonly perceived, and often have considerable durations.* Feeling being the subjective correlate of that which we know objectively as nervous action, these facts are obvious corollaries from facts set down in the last chapter. We there saw that the excitement of a nerve-centre involves waste; and that restoration of the nerve-centre to a state of equal susceptibility can be effected only by repair. Hence the return of fitness for what is objectively stimulation and subjectively feeling, will vary in quickness according to the rate of repair. When the blood is rich and rapidly circulated, the partial disability will be but momentary; and, unless the sensation has been intense, will be inappreciable. But along with failing nutrition of the tissues, the disability will become marked and its duration longer. In further illustration of this, I may name the fact that negative images are most conspicuous on awaking in the morning, when the circulation is slow. The sense of hearing yields parallel evidence; though evidence of which the parallelism is not

* This change comes on so gradually that very few remark it; and the usual supposition is that negative images are much the same at all ages and in all persons. I am able, however, to give personal testimony to the contrary. When about twenty years of age, my attention was drawn by my father to a case in which the circumstances were favourable for perceiving the negative image, and in which he perceived it clearly. To me it was invisible; and I well remember his remark, that I should begin to see such images as I became older. He was right. I now see them distinctly; and, moreover, I observe that they are most distinct at times of least vigour. It is worth while inquiring how far this change affects the appreciation of the chromatic harmonies. It seems inferable that the harmonies of complementary colours become more perceptible as life advances.

immediately obvious. Persons on whom old age or debility brings deafness, frequently describe themselves as having no difficulty in hearing sounds, but as being unable to disentagle and identify words when they are indistinctly or rapidly uttered. Supposing that in such cases the nervous structures concerned suffer from faulty nutrition, we have an explanation of this peculiarity. For if each of the successive sounds entails waste of the auditory centres, and leaves them less sensitive to like sounds, it must follow that, when re-integration is slow, the like sounds immediately afterwards received will produce less than their due amounts of sensation. These defects of sensation will show themselves most in a comparative deadness to those delicate consonantal modifications by which words are mainly distinguished from one another—the utterances listened to will seem a series of vowel-sounds joined by blurred consonants. Hence the reason why persons thus affected, ask those who address them to articulate slowly and clearly. The confusion of impressions produced by rapid speech on auditory centres thus debilitated, may be conceived by supposing debilitated optic centres to be similarly treated. If a person in whom the negative images are strong, has a series of objects passed before his eyes so fast that he can have only a momentary glance at each (to parallel the momentary opportunity which the ears have of identifying each successive articulation); then it will manifestly happen that the negative image of each object will interfere with, and confuse, the positive image of the next; and such a person will therefore not identify the successive objects so readily as one whose optic centres are repaired with normal speed. As confirming the belief that this defect of hearing is so caused, I may add that it frequently co-exists with the defect of vision to which I have compared it; and also that the one, like the other, is most marked early in the day, and is diminished by whatever invigorates the circulation.

§ 46. Another class of correlations demands a passing notice. Up to this point, the feelings considered have been subjective aspects of those changes which objectively are nervous stimulations. We have now to consider certain other feelings which are the inner faces of what on their outer faces are nervous discharges. Having traced pretty fully the concomitance of sentient states and *recipio-motor* acts, it will suffice to trace briefly the concomitance of sentient states and *dirigo-motor* acts.

Certain inferior *dirigo-motor* acts are unconscious; but omitting these, the law is that with each muscular contraction there goes a sensation more or less definite. This is not a sensation indirectly produced through the nerves proceeding inwards from the skin, some of which are nearly always disturbed by each bodily motion; but it is a sensation directly produced, either by the discharge itself or by the state of the muscle or muscles excited. It is most clearly distinguished when, without touching anything and without moving, a leg or arm is held out at right angles to the body.

Vague as are feelings of this class in comparison with most feelings accompanying nervous stimulations, and much less numerous as are the varieties of quality among them, they are nevertheless so far definite and different that we can, to a certain extent, recognize the separate feeling belonging to each separate contraction. We are aware without looking at it, and without touching anything with it, which finger has been bent by the discharge sent to its flexor muscles; and, by the particular combination of feelings accompanying the act, the placing of a limb in a given attitude is present to consciousness without aid from the eyes or hands. I say we can to a certain extent recognize the changes we thus set up; because the differences among the sensations of muscular tension soon lose much of their distinctness. It is a curious fact that when a limb has been held for some time in any position, especially if the position is one involving but little strain, the subjective state asso-

ciated with the nervous discharge to its muscles, becomes so indefinite that the attitude of the limb is unknown, if there does not happen to be a recollection of it.

Besides the connection between what we know objectively as a particular motor act, and subjectively as a particular feeling of muscular tension, there is a connection between the accompanying motor excitement propagated throughout the muscular system, and a certain diffused feeling of which it is the seat. How along with each special nervous discharge there goes a general nervous discharge, we saw in the last chapter; and here we recur to the relation only to observe that there is a parallel relation between the concomitant states of consciousness. Thus the vivid sensation caused by putting the foot into scalding water, does not lead only to the muscular contractions and muscular feelings which accompany the sudden withdrawal of the leg, but also to contractions of countless other muscles throughout the body, and a feeling called a shock or start.

Nor are these subjective states, special and general, that accompany special and general discharges to the muscles, the only subjective states that accompany discharges. As before pointed out, the vascular system and the alimentary system receive their shares of each discharge—very appreciable when it is intense, and probably in no case wanting; and these, too, present inner aspects to consciousness. Sometimes, indeed, the feelings that go along with discharges into the vaso-motor and sympathetic nerves, are the predominant ones; as instance the thrill diffused through the body by certain acute creaking sounds said to "set the teeth on edge;" or the nausea produced by particular kinds of disagreeable odours.

§ 47. Are these correlations between nervous actions and the concomitant feelings quantitative? Is there such connection between a physical change in the nervous system and the psychical change accompanying it, that we may

regard the one as an equivalent of the other, in the same sense as we regard so much heat as the equivalent of so much motion? The reader will perhaps expect an affirmative answer; but if an affirmative answer is to be given, it must be given in a greatly-qualified form.

On remembering that many nervous actions are always unconscious; on also remembering that various objective states of the nervous system which have associated subjective states early in life, cease to have them later in life; and on remembering, further, that at the same period of life a change set up in an afferent nerve may cause an appreciable feeling, or may not cause it, according as the attention is free or occupied; we shall see that the connection between feelings and nervous changes is conditioned in a very complex way, and that if they are quantitatively related it can be only within the narrow limits implied by the complex conditions. If between a purely voluntary act and a purely automatic act there are gradations—if, at the one extreme, feeling is a conspicuous accompaniment, and, at the other extreme, ceases to be an accompaniment; then, clearly, in the intermediate phases the amount of feeling must bear a varying ratio to the amount of nervous change which the act implies. Again, if we assume that what is present to consciousness as a sensation of given strength, is the correlate of a proportionate molecular disturbance in all the nervous structures concerned, how shall we interpret the sensations distinguished as subjective? In sundry abnormal states, strong feelings of cold or heat are felt throughout the body, though its actual temperature has remained unaltered. As in any case of this kind the total nervous change cannot have been the same as if the skin had fallen or risen in temperature to the degree ordinarily required to produce the feeling, we cannot say that there is a quantitative equivalence between the amount of nervous change and the amount of feeling. The disagreeable smell

which, on the approach of a fit, the epileptic patient frequently complains of, affords a yet better illustration. Here the outer ends of the afferent nerves being undisturbed, and only certain central structures irritated, the quantity of nervous action is not the same as if the sensation had been generated by an actual smell. More conspicuously still do we see the variability of this relation, when we compare the feelings called efforts with the discharges and muscular strains produced by them under different conditions. If the psychical force known as effort were transformable into a constant quantity of physical force, then, in any two cases, equal efforts should produce equal contractions. But they do not. Great exertion in a child fails to evolve from its motor organs the dynamic effect which a small exertion evolves from those of a man. Any one who is fatigued finds that an intenser feeling of strain is requisite to generate a given degree of muscular tension, than when he is fresh. And those prostrated by illness show us that immense expenditures of feeling are needed to perform acts which, during health, need scarcely appreciable expenditures of feeling. Doubtless these differences are partly due to differences in the muscles; which, when undeveloped or when wasted, are excited to smaller amounts of tension by equal amounts of discharge. But we must regard them as partly due to the imperfect development, or the worn state, of the intermediate motor centres and efferent nerves, in which a given feeling excites a smaller molecular disturbance than when they are finished in structure and in complete repair—a conclusion enforced by the familiar experience that purely nervous acts, as those of thought, require unusual efforts when the brain is tried.

This variability of the quantitative relation between nervous actions and psychical states, is equally seen when we limit our comparisons to those nervous actions and psychical states which occur in the same individual under

the same bodily conditions. To show that unlike but equally intense sensations may be produced by peripheral disturbances widely unlike in their amounts, providing they arise in different external sense-organs, is scarcely possible without comparing the amounts of the incident forces; and this we cannot properly do, since we are here confining our attention to correlations within the organism. We are similarly debarred from going at length into the quantitative contrasts between the muscular tensions produced by the same feeling of effort, according as the muscles excited are large or small; for we cannot well establish these contrasts without measuring the muscular tensions by the external actions they are equivalent to. There is, however, one class of appropriate cases—those in which irritations arising within the organism, set up sensations that cause undirected motor discharges. Violent toothache, for example, is due to waves of molecular change sent through one or two minute afferent nerve-fibres; but the bodily contortions show us that the feeling so produced, suffices to send waves of molecular change through various large bundles of efferent nerve-fibres, and to contract numerous muscles with much force. To which of these disturbances, centripetal or centrifugal, is the feeling equivalent? We cannot say to both, for one is many times the other in amount; and we have no reason to say that it is equivalent to one rather than to the other: the rational inference being that it is not equivalent to either.

To understand the real relations between objective and subjective changes in the nervous system, we need but to recall certain of the conclusions reached in preceding chapters. The essential principle of nervous organization we have seen to be that the small amounts of motion received, liberate larger amounts, and these again still larger amounts. A disturbance in the end of an afferent nerve is multiplied as it traverses the nerve, and the degree of multiplication varies with the length of the

nerve; it is much more multiplied in the first ganglion reached, and increases further in traversing the centripetal nerve; it is again multiplied in the superior centre, to be afterwards augmented in its subsequent centrifugal course; and it is once more multiplied, probably in a far greater degree, in the contractile substance of the excited muscles. Hence the accompanying feeling, which is the subjective aspect of this disturbance at one of its intermediate stages, can be a quantitative equivalent neither of the initial nervous change nor of the terminal nervous change. Moreover, since the multiplication varies in degree, being much greater in the organs of the higher senses than in those of the lower, it follows that the ratio between the amount of feeling and the amount of initial change is far from constant; and the evidence clearly indicates a like inconstancy of the ratio between the amount of feeling and the amount of terminal change, according as one or other muscle or set of muscles is made to act.

How then can there be any quantitative relation, it will be asked. If there is no equivalence between a disturbance set up at the periphery and the produced feeling, and no equivalence between the produced feeling and the motor discharge that follows—if the feeling does not even bear the same ratio to either the initial or the terminal nervous change in different cases; what quantitative relation can there be? The reply is simple. There is a quantitative relation between nervous change and feeling when all other things remain the same; and there is a quantitative relation between feeling and resulting contraction when all other things remain the same. Supposing every condition to continue unaltered, then the stimulus conveyed through a given nerve to a given centre, will evoke a feeling that increases and decreases in something like the same proportion as the stimulus increases and decreases; and, supposing a given muscle to be contracted, then the amount of its contraction will bear a tolerably constant ratio to

the feeling of effort that accompanies the contraction of it. The nature of these correlations may best be expressed by numbers. If, coming through a given afferent nerve, a disturbance represented by 1 generates a feeling represented by 5, then disturbance 2 will generate feeling 10, and disturbance 5 feeling 25; and if, acting through a given efferent nerve, feeling 5 results in muscular tension 60, feeling 10 will result in muscular tension 120. But to complete this numerical expression of the facts we must suppose these ratios to vary with every set of afferent nerves and every set of efferent nerves. If we say that 1 to 5 represents the ratio of disturbance to feeling in the sense of touch, then to represent it in the sense of hearing will need, say, 1 to 100, and in the sense of sight perhaps 1 to 1,000; and similarly with the ratios throughout the motor apparatus, according as the muscles are large or small.

In brief, then, the quantitative correlation of feeling and nervous change, holds true only within narrow limits. We have good reason to conclude that at the particular place in a superior nervous centre where, in some mysterious way, an objective change or nervous action causes a subjective change or feeling, there exists a quantitative equivalence between the two: the amount of sensation is proportionate to the amount of molecular transformation that takes place in the vesicular substance affected. But there is no fixed, or even approximate, quantitative relation between this amount of molecular transformation in the sentient centre, and the peripheral disturbance originally causing it, or the disturbance of the motor apparatus which it may eventually cause.

§ 48. The feelings called sensations have alone been considered thus far; leaving out of view the feelings distinguished as emotions. Much less definite as they are, and not capable of being made at will the objects of ob-

servation and experiment, the emotions are more difficult to deal with. But having discerned certain general laws to which the simpler feelings conform, we may now ask whether, so far as we can see, they are conformed to by the more complex feelings. We shall find that they are.

The conditions essential to the one are essential to the other. Emotions, like sensations, may be increased or decreased in intensity by altering either the quantity or the quality of the blood. That general abundance of blood is a cause of emotional exaltation, though tolerably certain, is not easily proved; but there is sufficient evidence of the converse fact that, other things equal, depletion is a cause of apathy. The effect of local abundance of blood is undoubted: there is no question that, within limits, the amount of emotion varies as the amount of blood supplied to the great nervous centres. That nervous stimulants intensify the emotions, or, as we say, raise the spirits, is even more manifest than that they make the sensations keener. And it is a familiar truth that sedatives diminish what is distinguished as moral pain, in the same way that they diminish pain arising in the trunk or limbs.

That a feeling lasts an appreciable time, is no less true of an emotion than of a sensation: indeed the persistence is relatively conspicuous. The state of consciousness produced by a flash of lightning, is so brief as to seem instantaneous: only by the help of artificial tests are sensations of this kind found to have measurable durations. But no such tests are needed to prove that emotions continue through appreciable periods. Even a simple emotion, as of anger or fear, does not reach its full strength the moment the cause presents itself; and after the cause is removed it takes some time to die away. When hereafter we deal with the origin of emotions, and recognize the fact that they are of far more involved natures than sensations, and imply the co-operation of extremely intricate

nervous structures, we shall understand how this greater duration is necessitated.

That an emotion, like a sensation, leaves behind it a temporary incapacity, is also true; and as the emotion produced by a momentary cause lasts longer than a sensation produced by a momentary cause, so does the partial incapacity for a like emotion last longer than the partial incapacity for a like sensation. Passions of all kinds come in gushes or bursts. That they often continue for hours and days, is true; but they are never uniform throughout hours and days. Be it in grief, or joy, or tenderness, there is always a succession of rises and falls of intensity—a paroxysm of violent feeling with an interval of feeling less violent, followed by another paroxysm. And then, after a succession of these comparatively-quick alternations, there comes a calm—a period during which the waves of emotion are feebler: succeeded, it may be, by another series of stronger waves. As in the case of the sensations so in the case of the emotions, this follows from the fact that what is objectively a nervous action and subjectively a feeling, involves waste of the nervous structures concerned. The centres which are the seats of emotions undergo disintegration in the genesis of emotions; and, other things remaining equal, thereupon become less capable of generating emotions until they are re-integrated. I say, other things remaining equal, because the rise of an emotion brings blood to the parts implicated, and so long as the afflux is increasing the intensity of the emotion may increase, notwithstanding the waste that has taken place; but the several conditions on which activity depends having become constant, a diminished capacity for emotion inevitably follows each gush of emotion.

That daily rises and falls of strength, consequent on daily periodicities of waste and repair, occur in the emotions as in the sensations, is also tolerably manifest. Cultivated people, mostly leading lives that exercise

their brains too much and their muscles too little, and placed in social conditions that commonly bring the strongest excitements towards the close of the day, are subject to an abnormal periodicity. But those whose lives conform best to the laws of health, exhibit early in the day a general joyousness and emotional vivacity greater than they do towards its close, when approaching sleepiness is shown by a flagging interest in the things and actions around.

These complex feelings that are centrally initiated are also like the simple feelings that are peripherally initiated, in having general discharges as well as special discharges: indeed their general discharges are the more conspicuous of the two. A sensation is often visibly followed only by local movement: unless very strong its effect on the organism as a whole is unobtrusive. But an emotion, besides the more obvious changes it works in the muscles of the face, habitually works changes, external and internal, throughout the body at large. The respiration, the circulation, the digestion, as well as the attitudes and movements, are influenced by it even when moderate; and everyone knows how strong passions, pleasurable or painful, profoundly disturb the whole system.

§ 49. Nothing has yet been said about the most conspicuous and most important distinction existing among the feelings. Every feeling, besides its minor variations of intensity, exists under two strongly-contrasted degrees of intensity. There is a vivid form of it which we call an actual feeling, and there is a faint form of it which we call an ideal feeling. What is the nature of this difference as interpreted from our present stand-point?

When studying nerve-structure, we saw that, in addition to connections formed by grey matter between the central ends of afferent and efferent nerves, these have connections with centripetal and commissural nerves, which

are again connected with more distant nerves. And when studying nerve-function, we saw that a disturbance set up by an afferent nerve in its ganglion, does not affect exclusively the efferent nerve, but that part of it, conveyed through centripetal and commissural nerves, affects other centres, and these again others, until it has reverberated throughout the entire nervous system. What follows? These reverberations are feeble disturbances. And every centre, liable as it is to be strongly disturbed through its afferent or centripetal nerve, is liable also to be feebly disturbed by these reverberations arriving through other nerves. What then must happen with each of the *libero-motor* elements composing those higher centres in which nervous changes become changes of consciousness? When it is affected through the direct and fully-opened route, by that peripheral impression to which it stands organically related, it evolves much molecular motion, becomes an active propagator of disturbances throughout the nervous system, and is the seat of what we call a real feeling; but when it is affected by these secondary waves diffused from other strongly excited parts, it becomes, as compared with them (or with itself under the previous condition) a generator of but little molecular motion, and is the seat of that faint feeling which we distinguish as ideal. In brief, those vivid states of consciousness which we know as sensations, accompany direct and therefore strong excitations of nerve-centres; while the faint states of consciousness which we know as remembered sensations, or ideas of sensations, accompany indirect, and therefore weak, excitations of the same nerve-centres.

That the contrast of intensity between the effects of direct and indirect excitations, though it holds generally, does not hold without exception, is a fact quite reconcilable with this interpretation. For, on the one hand, a direct excitation may be very feeble; while, on the other hand, through a concurrence of diffused disturbances, an indirect

excitation may rise to considerable strength. Hence, occasionally, an ideal feeling will become almost or quite equal in vividness to a real feeling. Especially may this happen when the nerve-centre concerned is surcharged with blood; since a small disturbance may then set up in it an amount of change equal to that which a great disturbance produces when only the ordinary quantity of blood is present. And it is a matter of observation that congested nerve-centres are those in which indirectly-excited feelings reach an intensity scarcely less than that of directly-excited feelings.

When we pass from the feelings called sensations, of which the strong forms are peripherally initiated, to the feelings called emotions, of which the strong forms are centrally initiated, we find the difference between the strong and the weak forms by no means so great; so that, in fact, ideal emotion passes into actual emotion without any line of demarcation. Obviously this is what might be anticipated. For whether ideal or actual, emotion is an accompaniment of an indirect excitation: it is not an immediate result of peripheral impressions, either simple or combined; but a mediate or remote result of them. Hence, all emotions, vivid and faint, being the subjective aspects of objective nervous changes that are produced indirectly, are distinguishable only according to the degree of indirectness of the excitation, and this admits of insensible gradations.

§ 50. One more general truth must be set down to complete the outline. The foregoing inferences joined with some contained in the last chapter, introduce us to it.

In §§ 36, 37, it was pointed out that nerve-centres disintegrated by action, are perpetually re-integrating themselves, and again becoming fit for action. We saw that repair partially makes up for waste from instant to instant, and that the arrears of repair are made up daily during that period of quiescence when waste almost ceases. We

further saw that the restoration of a nerve-centre to its state of integrity, is not only the filling up of its quantum of decomposable matter, but is also the replacing of molecules most exposed to disturbance, and consequently the production of a comparatively-unstable state. And we saw how, after a period of profound repose, there thus arises a condition of the nerve-centres such that very slight stimuli cause nervous discharges.

This law applies not generally only, but specially to each nerve-centre and each of its component parts. In proportion as any part of a nerve-centre has been for a long time unused—in proportion, that is, as repair of it has gone on day after day and night after night unhindered by appreciable waste, it must be brought to a state of more than ordinary instability—a state of excessive readiness to decompose and discharge. What must happen? In common with all other parts, it is exposed to these reverberations which from instant to instant fill the nervous system. Its extreme instability must render it unusually sensitive to these reverberations—unusually ready to undergo change, to yield up molecular motion, and to become the seat of the concomitant ideal feeling. Besides a great liability to the ideal feeling this same condition must entail a great strength of it; and so while the instability continues, a strong ideal feeling will be perpetually aroused. As, however, the nerve-centre in which such secondary molecular changes and accompanying ideal feelings are thus set up, is somewhat wasted by them, it follows that after they have gone on for a considerable period the instability of the centre will be diminished: it will no longer be so easily decomposed by indirect disturbances, and the feeling will not be produced.

Here we have the interpretation of what are called *desires*. Desires are ideal feelings that arise when the real feelings to which they correspond have not been experienced for some time. They are then liable to be excited

by various of the indirect disturbances reflected from part to part of the nervous system. They are usually vivid and persistent in proportion to the previous period of rest—more vivid and more persistent than ideal feelings of the same kind under ordinary conditions. But after a prolonged period during which they continue to arise and almost monopolize consciousness, they become feebler and finally die away.

§ 51. Such are the leading truths of Æstho-Physiology, set forth with as much fulness as is here requisite. Sensation and emotion in their relations to nervous action, have been dealt with generally; and whatever has been said of special sensations and special emotions has been said merely to illustrate a law which holds among all the rest. The concomitants, subjective and objective, of each particular kind of sensation and each particular kind of emotion, I here pass over. They may be studied to great advantage in the works of Professor Bain on *The Senses and the Intellect*, and *The Emotions and the Will;* in which he has given an elaborate account of the connection between each particular feeling, simple or complex, and its various physical accompaniments. To these works I must commend the reader who wishes to trace out these minor correlations. As data for the present treatise, the only facts needful to be carried with us are those set forth in the preceding sections. They may be summed up thus.

Feeling of whatever kind is directly known by each person in no other place than his own consciousness. That feelings exist in the world beyond consciousness, is a belief reached only through an involved combination of inferences. That alike in human and inferior beings, feelings are accompaniments of changes in the peculiar structure known as the nervous system, is also an indirectly-established belief. And that the feelings alone cognizable by any individual are products of the action of his own

nervous system, which he has never seen and on which he can try no experiments, is a belief only to be arrived at through a further chain of reasoning. Nevertheless, the evidence, though so indirect, is so extensive, so varied, and so congruous, that we may accept the conclusion without hesitation.

The conclusion having been accepted—provisionally if not permanently—its validity is shown by leading us to anticipate truly, in one set of cases after another, the particular subjective phenomena that accompany particular objective phenomena. We have seen that the several circumstances which facilitate or hinder nervous action, are also circumstances which facilitate or hinder feeling. We have seen that as nervous action occupies appreciable time, so feeling occupies appreciable time. We have seen that each feeling leaves a partial incapacity for a like feeling, as each nervous action leaves a partial incapacity for a like nervous action. We have seen that, other things equal, the intensities of feelings vary as the intensities of the correlative nervous actions. We have seen that the difference between direct and indirect nervous disturbances, corresponds to the difference between the vivid feelings we call real and the faint feelings we call ideal. And we have seen that certain more special objective phenomena which nervous actions present, have answering subjective phenomena in the forms of feeling we distinguish as desires.

Thus, impossible as it is to get immediate proof that feeling and nervous action are the inner and outer faces of the same change, yet the hypothesis that they are so harmonizes with all the observed facts; and, as elsewhere shown (*First Principles*, § 40) no other verification is possible for us than that which results from the establishment of complete congruity among our experiences.

CHAPTER VII.

THE SCOPE OF PSYCHOLOGY.

§ 52. We may now enter on our special topic. Thus far we have been occupied with the data of Psychology, and not with Psychology properly so-called. Here leaving the foundations we pass to the superstructure.

Not a few readers will be surprised by the assertion that none of the truths we have been contemplating are psychological truths. Since the anatomy and physiology of the nervous system have occupied so much attention, and since it has been growing manifest that there is a fundamental connection between nervous changes and psychical states, there has arisen a confusion between the phenomena which underlie Psychology and the phenomena of Psychology itself. In reality, all the facts ascertained by those who have made nerve-structure and nerve-function their studies, are facts of a simpler order than those rightly termed psychological; though they are facts entering into the composition of psychological facts.

Most will admit without hesitation that the first five chapters of this part consist of propositions which are exclusively morphological and physiological. In them the structure of the nervous system, its functions, the conditions to its action, &c., have been dealt with purely as physical phenomena—phenomena as purely physical as the absorption

of nutriment or the circulation of the blood. Whatever implications may have arisen from the use of words that carry with them indirect meanings, the direct meanings of all the propositions set down have nowhere implied consciousness or feeling; and, ignoring consciousness or feeling, they have left out that which is tacitly or avowedly contained in every proposition of Psychology.

It will probably be thought, however, that at any rate truths belonging to Psychology proper are to be found in the last chapter. Dealing as the last chapter does with the connections between nervous changes and feelings, it necessarily becomes, by including a psychical element, a part of psychical science. To this the rejoinder is that, though it can scarcely be excluded absolutely from the body of this science, yet it does not strictly fall within that body. Æstho-physiology has a position that is entirely unique. It belongs neither to the objective world nor the subjective world; but taking a term from each, occupies itself with the correlation of the two. It may with as much propriety be included in the domain of physical science as in the domain of psychical science; and must be left where it stands, as the link between them.

Perhaps this explanation will increase rather than decrease the surprise produced by the assertion that was to be justified. To clear up the confusion, we must examine more carefully the distinction between the truths which are strictly psychological and those which merely enter into the composition of psychological truths.

§ 53. Throughout the preceding chapters, including even the last, every proposition set down has expressed some relation of phenomena occurring within the limits of the organism. The subject-matter has been the character of a structure; or the effect which a disturbance set up in one place has in causing motion in another; or the connection between the physical state of the whole or a part of the

organism, and some general or local nervous process; or the variable intensity of an action in a nerve-centre as determined by a preceding like action; or the interdependence of internal physical changes and internal psychical changes. That is to say, the attention has everywhere been directed exclusively to co-existences and sequences of which the body alone is the sphere. Distinct or tacit reference has, indeed, frequently been made to some external force. Either a disturbing agent lying beyond the limits of the organism has been referred to in general terms, or, for illustration's sake, this or the other kind of disturbing agent has been named. But such references, vague or distinct, have been made merely because it was needful to suppose something by which an organic change was set up; not because this something had to be included in the proposition set down, which in every case formulated an internal relation only. The entanglement of phenomena is such, that we can never cut off absolutely from all others the particular phenomena we are dealing with; but, because we presuppose these other phenomena, it does not follow that the science to which they pertain forms part of the science with which we are specially occupied. For instance, it is impossible to describe, or think of, a chemical experiment that discloses some chemical relation, without making distinct or tacit references to physical relations—the pouring and mixture of liquids, the ascent of bubbles of disengaged gas, the falling of a precipitate; but it is not therefore held that we are including physics in our chemistry. Similarly, it must be admitted that though the foregoing chapters have tacitly assumed environing forces, yet this assumption has been simply incidental to the study of internal co-existences and sequences.

Now so long as we state facts of which all the terms lie within the organism, our facts are morphological or physiological and in no degree psychological. Even though the relation with which we are dealing is that between a

nervous change and a feeling, it is still not a psychological relation so long as the feeling is regarded merely as connected with the nervous change, and not as connected with some existence lying outside the organism. As certainly as the man who demonstrates by dissection the articulations of the bones, and the man who, by a sphygmograph, delineates the varying motions of the heart, are respectively studying morphology and physiology; so certainly is the man who examines nervous structure and experiments on nervous function, a student of these same sciences, if he considers the inner correlations only and does not simultaneously consider the answering outer correlations.

For that which distinguishes Psychology from the sciences on which it rests, is, that each of its propositions takes account both of the connected internal phenomena and of the connected external phenomena to which they refer. In a physiological proposition an inner relation is the essential subject of thought; but in a psychological proposition an outer relation is joined with it as a co-essential subject of thought. A relation in the environment rises into co-ordinate importance with a relation in the organism. The thing contemplated is now a totally different thing. It is not the connection between the internal phenomena, nor is it the connection between the external phenomena; but it is *the connection between these two connections.* A psychological proposition is necessarily compounded of two propositions, of which one concerns the subject and the other concerns the object; and cannot be expressed without the four terms which these two propositions imply. The distinction may be best explained by symbols. Suppose that A and B are two related manifestations in the environment—say, the colour and taste of a fruit; then, so long as we contemplate their relation by itself, or as associated with other external phenomena, we are occupied with a portion of physical science. Now suppose that *a* and *b* are the sensations produced in the organism by this peculiar light which the fruit

reflects, and by the chemical action of its juice on the palate; then, so long as we study the action of the light on the retina and optic centres, and consider how the juice sets up in other centres a nervous change known as sweetness, we are occupied with facts belonging to the sciences of Physiology and Æstho-physiology. But we pass into the domain of Psychology the moment we inquire how there comes to exist within the organism a relation between *a* and *b* that in some way or other corresponds to the relation between A and B. Pyschology is exclusively concerned with this connection between (A B) and (*a b*)—has to investigate its nature, its origin, its meaning, &c.

A moment's introspection will now make it clear to the reader, that he cannot frame any psychological conception without thus looking at internal co-existences and sequences in their adjustments to external co-existences and sequences. If he studies the simplest act of perception, as that of localizing a touch in some part of his skin, the indispensable terms of his inquiry are:—on the one hand a thing (1) and a position (2), both of which he regards as objective; and on the other hand a sensation (3), and a state of consciousness constituting his apprehension of position (4), both of which he regards as subjective. Again, to cite an example from the opposite extreme, if he takes for his problem one of his involved sentiments, as that of justice, he cannot represent to himself this sentiment, or give any meaning to its name, without calling to mind actions and relations supposed to exist in the environment: neither this nor any other emotion can be aroused in consciousness even vaguely, without positing something beyond consciousness to which it refers. And when, instead of studying Psychology subjectively, he studies it objectively in the acts of other beings, he similarly finds himself incapable of stirring a step without thinking of inner correlations in their references to outer correlations.

§ 54. It is contended by some that Psychology is a part of Biology, and should be merged in it; and those who hold this view will possibly answer the above argument by saying that in many cases the non-psychological part of Biology also takes into account phenomena in the environment, and even definite connections among these phenomena. The life of every organism is a continuous adaptation of its inner actions to outer actions; and a complete interpretation of the inner actions involves recognition of the outer actions. The annual production of leaves, flowers, and seeds by plants, is adjusted to the annual changes of the seasons; and there is in animals an adjustment between external changes in temperature and abundance, and internal production of ova. Moreover, there are many special relations of structure and function in plants and animals, that have reference to special relations of structure and function in surrounding plants and animals: instance those arrangements of the sexual organs that fit particular phænogams for being fertilized by the particular insects that visit them.

But true as is this conception of Life (and having based the *Principles of Biology* on it I am not likely to question or to undervalue it), I nevertheless hold the distinction above drawn to be substantially valid. For throughout Biology proper, the environment and its correlated phenomena are either but tacitly recognized, or, if overtly and definitely recognized, are so but occasionally; while the organism and its correlated phenomena practically monopolize the attention. But in Psychology, the correlated phenomena of the environment are at every step avowedly and distinctly recognized; and are as essential to every psychological idea as are the correlated phenomena of the organism. Let us observe the contrast as exemplified. We study digestion. Digestion implies food. Food implies neighbouring plants or animals. But this implication scarcely enters into our study of digestion,

unless we ask the quite special question—how the digestive organs become fitted to the materials they have to act upon? Again, when we interpret respiration we take for granted a surrounding oxygenated medium. And yet to show how far the two may be separated, we need only remember that the phenomena of respiration may be very well traced out in one who breathes a bladder of gas artificially obtained from peroxide of manganese or chlorate of potash. Once more, if, in following out the life-history of a plant, we have to note the adaptation of its hooked seeds to the woolly fleece of the animal which accidentally carries them off and disperses them, this distinct reference to specially-connected phenomena in the environment, occurs either but once in an account of the plant's life, or only at long intervals. In fact, we may say that the great mass of purely biological phenomena may be displayed for some time by an organism detached from its medium, as by a fish out of water. Now observe how different it is with psychological phenomena. We cannot explain a single act of a fish as it moves about in the water, without taking into account its relations to neighbouring objects distinguished by specially-related attributes. The instinctive proceedings of the insect, equally with those which in higher creatures we call intelligent, we are unable even to express without referring to things around.

In brief, then, the propositions of Biology, when they imply the environment at all, imply almost exclusively its few general and constant phenomena, which, because of their generality and constancy, may be left out of consideration; whereas the propositions of Psychology refer to its multitudinous, special, and ever-varying phenomena, which, because of their speciality and changeability, cannot be left out of consideration.

§ 55. The admission that Psychology is not demarcated from Biology by a sharp line, will perhaps be construed

into the admission that it cannot rightly be regarded as a distinct science. But those who so construe the admission, misconceive the natures of the relations among the sciences. They assume that there exist objectively those clear separations which the needs of classification lead us to make subjectively. Whereas the fact is, that beyond the divisions between the three fundamental orders of the sciences, Abstract, Abstract-concrete, and Concrete, there exist objectively no clear separations at all: there are only different groups of phenomena broadly contrasted but shading off one into another. To those who accept the doctrine of Evolution, this scarcely needs saying; for Evolution being a universal process, one and continuous throughout all forms of existence, there can be no break—no change from one group of concrete phenomena to another without a bridge of intermediate phenomena. It will be well here, however, to show by illustrations that the simpler concrete sciences are separable from one another only in the same way that Psychology is separable from Biology.

Astronomy and Geology are regarded as distinct. But Geology is nothing more than a chapter continuing in detail one part of a history that was once wholly astronomic; and even now, many of its leading facts belong as much to the older part of the history as to the younger. Not only do we trace back the Earth to a time when its astronomic attributes were uncomplicated by those geologic ones that have gradually arisen as it cooled; not only in the solar heat, causing the aërial, marine, and fluvial currents which work most geologic changes, are we compelled to recognize an astronomic force; but in the tidal wave we have a phenomenon as much astronomic as geologic, and as much geologic as astronomic. Even he who arbitrarily excludes from astronomy everything but the molar motions throughout the Solar System (so ignoring the radiant light and heat by which alone the Sun and planets are known to us) does not escape this difficulty;

for the motion of the tidal wave is a molar motion generated by forces such as generate all other molar motions exhibited by the Solar System; and yet it is at the same time a motion of matter on the Earth's surface, not distinguishable from those other motions of matter which constitute geological changes, many of which, indeed, are concomitants of it. The separation between Biology and Geology once seemed impassable; and to many seems so now. But every day brings new reasons for believing that the one group of phenomena has grown out of the other. Organisms are highly-differentiated portions of the matter forming the Earth's crust and its gaseous envelope; and their differentiation from the rest has arisen, like other differentiations, by degrees. The chasm between the inorganic and the organic is being filled up. On the one hand, some four or five thousand compounds once regarded as exclusively organic, have now been produced artificially from inorganic matter; and chemists do not doubt their ability so to produce the highest forms of organic matter. On the other hand, the microscope has traced down organisms to simpler and simpler forms until, in the *Protogenes* of Professor Haeckel, there has been reached a type distinguishable from a fragment of albumen only by its finely-granular character.

Thus the distinction between Biology and Psychology has the same justification as the distinctions between the concrete sciences below them. Theoretically, all the concrete sciences are adjoining tracts of one science, which has for its subject-matter, the continuous transformation which the Universe undergoes. Practically, however, they are distinguishable as successively more specialized parts of the total science—parts further specialized by the introduction of additional factors. The Astronomy of the Solar System is a specialized part of that general Astronomy which includes our whole Sidereal System; and becomes specialized by taking into account the revolutions and rotations of planets

and satellites. Geology (or rather Geogeny let us call it, that we may include all those mineralogical and meteorological changes which the word Geology, as now used, recognizes but tacitly) is a specialized part of this special Astronomy; and becomes specialized by joining with the effects of the Earth's molar motions, the effects of continuous decrease in its internal molecular motion, and the effects of the molecular motion radiated from the Sun. Biology is a specialized part of Geogeny, dealing with peculiar aggregates of peculiar chemical compounds formed of the Earth's superficial elements—aggregates which, while exposed to these same general forces molar and molecular, also exert certain general actions and reactions on one another. And Psychology is a specialized part of Biology, limited in its application to the higher division of these peculiar aggregates, and occupying itself exclusively with those special actions and reactions which they display, from instant to instant, in their converse with the special objects, animate and inanimate, amid which they move.

But this introduction of additional factors, which differentiates each more special science from the more general science including it, fails in every case to differentiate it absolutely; because the introduction of the additional factors is gradual. It is so not with the Concrete Sciences alone, but even with the Abstract-concrete Sciences, which at first sight seem sharply demarcated; as, for instance, Physics and Chemistry. Physics, dealing with changes in the distribution of matter and motion considered apart from unlikenesses of quality in the matter, is obliged to include in its inquiries all the molecular integrations and disintegrations caused by alterations of temperature—the meltings and evaporations which increase of heat produces, as well as the condensations and crystallizations which follow decrease of heat. Among other molecular transformations resulting from losses and gains of molecular motion, are those known as allotropic—transformations which, without

appreciably altering the degrees of integration, leave the molecules so re-arranged that they exhibit new properties of the order we call chemical; as is shown by their changed affinities for the molecules of other substances, and by their changed effects on our nerves of sense. Must we class such molecular transformations as physical phenomena, because in each case the molecules concerned are all of one kind? If so, what are we to say of isomeric transformations, which all chemists recognize as of essentially the same nature? In these, molecules of different kinds are concerned. And if, because they show us a re-distribution of heterogeneous molecules instead of homogeneous ones, we put them in the category of chemical phenomena, we arbitrarily dissociate two fundamentally-similar classes of facts. Perhaps it will be replied that in isomeric transformations the molecules *are* homogeneous, relatively to the re-distribution they undergo; that each of them, retaining its individuality unchanged, comports itself towards the rest as though it were a simple molecule; that nothing more takes place than a re-grouping of these unchanged molecules; and that there is thus an absence of what constitutes a truly chemical change—union or disunion of unlike molecules. The reply is plausible, but it is easily disposed of. For there are transformations of this nature in which such unions and disunions occur. A colloid compound in passing from one of its isomeric forms to another, very generally parts with some of its contained water, or takes up additional water. Does this make the change a chemical one? Then we must relegate to the domain of Physics that isomerism which is not accompanied by loss or gain of water, and include in the domain of Chemistry that isomerism which is so accompanied—a very artificial disunion of the sciences, to which I think neither Physicists nor Chemists will agree. Nevertheless, undecided as is the line which separates them, we are not prevented from recognizing the broad distinction between Molecular Physics and Chemistry. The new factor which

differentiates Chemistry from Molecular Physics, is the heterogeneity of the molecules with whose re-distributions it deals. And the contrast hence resulting is too strongly marked to be obliterated by transitional cases.

In this way it is, then, that the conspicuous presence of additional factors differentiates Psychology from Biology proper; although in Biology proper these factors make an occasional appearance. The contrast between the two is no more destroyed by such community as exists, than is the contrast between night and day destroyed by the occurrence of a dawn which belongs as much to one as to the other.

§ 56. A far more radical distinction remains to be drawn. While, under its objective aspect, Psychology is to be classed as one of the concrete sciences which successively decrease in scope as they increase in speciality; under its subjective aspect, Psychology is a totally unique science, independent of, and antithetically opposed to, all other sciences whatever. The thoughts and feelings which constitute a consciousness, and are absolutely inaccessible to any but the possessor of that consciousness, form an existence that has no place among the existences with which the rest of the sciences deal. Though accumulated observations and experiments have led us by a very indirect series of inferences (§ 41) to the belief that mind and nervous action are the subjective and objective faces of the same thing, we remain utterly incapable of seeing, and even of imagining, how the two are related. Mind still continues to us a something without any kinship to other things; and from the science which discovers by introspection the laws of this something, there is no passage by transitional steps to the sciences which discover the laws of these other things.

Following M. Comte, there are a few who assert that a subjective Psychology is impossible; and to such the above paragraph will, I suppose, be meaningless. But whoever recognizes a subjective Psychology, and admits, as he must,

that without it there can be no objective Psychology, thereupon finds himself obliged to assign a quite special rank, not to the first only, but, by implication, to the second. To those who see that the essential conceptions on which Psychology in general proceeds, are furnished by subjective Psychology—to those who see that such words as feelings, ideas, memories, volitions, have acquired their several meanings through self-analysis, and that the distinctions we make between sensations and emotions, or between automatic acts and voluntary acts, can be established only by comparisons among, and classifications of, our mental states; it will be manifest that objective Psychology can have no existence as such, without borrowing its data from subjective Psychology. And thus perceiving that, until it acknowledges its indebtedness to subjective Psychology, objective Psychology cannot legitimately use any terms that imply consciousness, but must limit itself to nervous co-ordinations considered as physical only; they will see that even objective Psychology contains an element which differentiates it from the rest of the special concrete sciences more than any of these are differentiated from one another.

The claims of Psychology to rank as a distinct science, are thus not smaller but greater than those of any other science. If its phenomena are contemplated objectively, merely as nervo-muscular adjustments by which the higher organisms from moment to moment adapt their actions to environing co-existences and sequences, its degree of speciality, even then, entitles it to a separate place. The moment the element of feeling, or consciousness, is used to interpret nervo-muscular adjustments as thus exhibited in the living beings around, objective Psychology acquires an additional, and quite exceptional, distinction. And it is further distinguished in being linked by this common element of consciousness, to the totally-independent science of subjective Psychology—the two forming together a double science which, as a whole, is quite *sui generis*.

§ 57. So understanding its scope, we are now prepared to enter on the study of Psychology proper. The foregoing discussion serves not unfitly to introduce the several divisions into which the entire subject falls.

First come the Inductions of Psychology; under which title we will deal with the leading empirical generalizations—presenting them, however, under an aspect somewhat different from the usual one. And the truths inductively reached will, when possible, be elucidated deductively, by affiliating them on the truths of Neuro-physiology and Æstho-physiology set down in the foregoing chapters.

We will next pass to Objective Psychology; of which three divisions may conveniently be made. In the first, or General Synthesis, we will trace throughout the animal kingdom, the progress in these perpetual adjustments of special inner actions to special outer actions, which accompanies increasing evolution of the nervous system—omitting, so far as may be, the element of consciousness. In the second, or Special Synthesis, we will consider this same progress more closely, with the view of delineating and formulating it in terms that imply consciousness. And in the third, or Physical Synthesis, an endeavour will be made to show how, by an ultimate principle of nervous action, this progress is explicable as part of Evolution in general.

Turning then to Subjective Psychology, the natures of particular modes of consciousness, as ascertained by introspection, will first be treated under the head of Special Analysis. And then, under the head of General Analysis, we will enter upon the ultimate question of the relation between Thought and Things.

Two remaining divisions will be devoted, the one to a comparison between the results reached in the preceding divisions, with a view of showing their congruity, and the other to a series of corollaries constituting that special part of Human Psychology on which Sociology must be based.

The Conversion of the Roman Empire. The Boyle Lectures for the Year 1864, delivered at the Chapel Royal, Whitehall, by Charles Merivale, B. D., Rector of Lawford, Chaplain to the Speaker of the House of Commons, author of "A History of the Romans under the Empire." Large 12mo. Price, cloth, $2.

Principles of Political Economy, with some of their Applications to Social Philosophy. By John Stuart Mill. From the fifth London edition, 2 vols., small 8vo, handsomely printed. Cloth, $7; half calf, extra, $12.

The Vegetable World; being a History of Plants, with their Botanical Descriptions and peculiar Properties. By Louis Figuier, author of the "World before the Deluge." Illustrated with 446 Engravings interspersed through the text, and 24 full-page Illustrations, chiefly drawn from Nature, by M. Faguet, Illustrator to the Botanical Course of the Faculty of Sciences of Paris. 1 vol., 8vo, beautifully printed. 584 pages. Cloth, $6; half calf, $8.50; full calf, $10.50.

Thirty Years' View; or, a History of the Working of the American Government for Thirty Years, from 1820 to 1850; chiefly taken from the Congress Debates, the private papers of General Jackson, and the Speeches of ex-Senator Benton, with his actual view of men and affairs. With Historical Notes and Illustrations, and some notices of eminent deceased contemporaries. By Thomas H. Benton. 2 vols., 8vo. Cloth, $8; half calf, extra, $13.

The Harvest of the Sea; a Contribution to the Natural and Economic History of the British Food Fishes. By James G. Bertram. With fifty Illustrations. 1 large vol., 8vo, 520 pages. Cloth, $7.50; half calf, $10.

The Harmonies of Nature; or, the Unity of Creation. By Dr. G. Hartwig, author of "The Sea and its Living Wonders," and "The Tropical World." With eight full-page Drawings, and nearly two hundred Woodcuts. 1 vol., 8vo, 406 pages. Cloth, $7.50; half calf, extra, $10; full calf, extra, $12.

History of the Romans under the Empire. By Charles Merivale, B. D., late Fellow of St. John's College. 7 vols., small 8vo, handsomely printed on tinted paper. Price, cloth, $21; half calf, extra, $35.

Haydn's Dictionary of Dates, relating to all Ages and Nations, for Universal Reference. Twelfth edition. Revised, Enlarged, and Corrected to February, 1866. By Benjamin Vincent. 1 vol., large 8vo, 833 pages. Cloth, $7.50.

Metallurgy. Embracing the Elements of Mining Operations, and Analysis of Ores; a full description of all Smelting and other Operations for the production of Metals from the Ores. By T. Overman. With numerous Wood Engravings of Machinery, Furnaces, and Apparatus. A vol., 8vo, of over 600 pages. Cloth, $8.

The Works of Lord Macaulay. Complete. Edited by his Sister, Lady Trevelyan. With Portrait, engraved on steel, by W. Holl. 8 vols., large 8vo. Cloth, $40; half calf, extra, $56.

Correlation and Conservation of Forces; a Series of Expositions by Prof. Grove, Prof. Helmholtz, Dr. Mayer, Dr. Faraday, Prof. Liebig, and Dr. Carpenter; with an Introduction and brief Biographical Notices of the chief Promoters of the New Views, by Edward L. Youmans, M. D. Cloth, $2.50.

Appletons' Cyclopædia of Biography, Foreign and American, embracing a series of Original Memoirs of the Most Distinguished Persons of all Times. Edited by Francis L. Hawks, D. D., LL. D. With over 600 Engravings. 1 very large vol., 8vo. Cloth, $7; sheep, $8; half calf, extra, $10.

Cyclopædia of American Eloquence: a Collection of Speeches and Addresses by the most eminent Orators of America; with Biographical Sketches and Illustrative Notes. By Frank Moore. Two handsome volumes, large 8vo, embellished with the finest steel-plate Portraits. Cloth, $8; half calf, extra, $13.

History of Civilization in England. By Henry Thomas Buckle. With copious Index (not in the English edition). Two large volumes, 8vo, beautifully printed. Cloth, $8; half calf, extra, $13.